Exploring Farmers' and Pesticide Retailers' Perceptions and Practices towards the Deployment of Pesticides in the Sultanate of Oman

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This thesis submitted for the Degree of Doctor of Philosophy

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January 2022

‘Declaration

I confirm that this is my own work and the use of all materials from other sources has been properly and fully acknowledged.’

Mahmoud Mohammed Shamis Al Nabhani

Acknowledgments

I would like to express my thanks to everyone who helped me in the completion of my PhD thesis and research. My great thanks to my supervisors for their best and continuous effort, support and advice throughout my research. Prof. Alistair J. Murdoch, Prof. Michael L. Deadman and Prof. Peter Dorward, your guidance, support and advice has been greatly valuable.

I would also like to state my thanks to my colleagues in the Ministry of Agriculture and Fisheries who spared me their time and effort that helped me completing the thesis work - Dr. Nasr Subhi, Hanan Al Zakwani, Mohammed Isam, Sultan Al Rawahi and Iman Al Hosni. My many thanks also to all agriculture development directorates and centres in the research areas for the help in the field visits to non-farmers' association members which, without their help, I couldn't have got into most of the farms and collected the information or data required. My thanks also go to Mr. Saeed Al Kharusi, chairman of Farmers' Association, for his help, time and support in contacting, convincing and gathering Farmers' Association members to participate as respondents and in focus group discussions as well. I would particularly like to thank all the farmers who participated in this work for their time, support, help and enthusiasm in the participation as respondents in the farm survey work. Many thanks to Ganim Al Dohani from Al Musanah, Mahmoud Al Malki from Barka and Maheish from Barka for their support and agreement to open their farms and the farms under their management to allow me to carry out the spatial variability field research. Great thanks are due to Mss. Manahil Al Toubi and Mr. Ahmed Al Sulemi for their effort and support in ArcMap analysis to prepare spatial variability maps of pesticide deposition.

Special thanks to the Agriculture and Fisheries Funds and Ministry of Agriculture and Fisheries and Water Resources in Oman for financing this research and study leave and great thanks to all staff who support, help and effort in these regards.

My deep profound appreciation I reserve to my mother and my late father who was willing to celebrate the success with me, for my best wife, my sons and daughters and my family who believed on me for their patience and support. I appreciate every moment you struggled with me throughout my study period.

Abstract

This study was carried out to understand farmers' and pesticide retailers' perceptions and practices on pesticides for field vegetables in Oman. Covering seven governorates in Oman, 160 farmers and 75 pesticide retailers were surveyed. Results distinguished the 40 farmers belonging to the Farmers Association (FA) from those who did not (nFA).

FA respondents diagnosed common pests and diseases of vegetables in Oman better than nFA respondents. At least 50% of both groups could identify problems and knew which pesticide to use, but the remainder could not. Around half of FA recommended the correct dose rate and pre-harvest interval (PHI) compared to about 30% of nFA.

On health and safety, 77% of FA identified the potential risks of pesticides to humans and the environment, whereas 60% of nFA indicated there were no possible risks. Nearly one third of all respondents never wore PPE while using pesticides. Most FA respondents (68%) claimed that they "usually and always" read the label safety instructions in contrast to only 14% of nFA.

Although they were the main source of advice to farmers, many pesticide sellers failed to identify many of the pests and diseases (50%), select the proper pesticide (70%), or recommend the correct dose rate (37%) and PHI (44%). Forty-one percent "never" read the label safety instructions and 27% "never" explained health and safety risks to customers.

Spatial variability of pesticide application in three fields highlighted the variable coverage achieved using high pressure sprayers, the coefficient of variation always exceeding 30%. In a further field, the farm was targeting over twice the recommended rate.

In conclusion, there is an urgent need to introduce training for all stakeholders including farmers, pesticide retailers and government extension officials to improve crop protection capabilities and awareness of IPM. A programme to phase out high pressure sprayers is recommended.

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List of abbreviations and symbols

FA: Farmers' Association

nFA: Non-farmer association

MAFWR: Ministry of Agriculture and Fisheries and Water Resources

NCSI: National Centre for Statistics and Information

MoH: Ministry of Health

GCC: Gulf Cooperative Council countries

EPA: Environmental Protection Agency

WHO: World Health Organization

FAO: Food and Agriculture Organisation of the United Nations

IARC: International Agency for Research on Cancer

CAOL: Central Agricultural Pesticides Laboratory

CIPAC: Collaborative International Pesticides Analytical Council

EC: European Commission

PHI: Pre-harvest interval

PRC: Pesticides registration committee

CV: Coefficient of variation

CP: Crop protection

PPE: Personal protective equipment

IPM: Integrated pest management

RSS: Residual sum of squares

AI: Active ingredient

%: Percentage

ha: Hectare

KW: Kilo watt

KPa: Kilo pascal

Chapter 1. Introduction.

1. Agriculture in Oman

The Sultanate of Oman occupies the South-Eastern corner of the Arabian Peninsula and is located between Latitudes 40 and 26 20 North and Longitudes 51 50 and 59 16 (NCSI, 2020). The total population of the country is 4.49million (NCSI, 2021). The climatic conditions vary from arid and hot in summer when the temperatures rise up to 45ºC to warm and cool in winter when the temperatures fall to 15°C in most regions except the elevated mountains such as Al Jabal Al Akhdar and Jabal Shams mountains (2980m and 3009m respectively). Administratively, the country is divided into eleven governorates namely: Muscat (the capital), Ad Dakhliyah, Adh Dhahirah, Al Batinah North, Al Batinah South, Ash Sharqiyah North, Ash Sharqiyah South, Dhofar, Al Buraimi, Musandam, and Al Wusta (NCSI, 2020) (Figure 1.1). The twelve governorates are subdivided into sixty-one wilayats and these wilayats are also sub-subdivided into villages. Agriculture plays a vital role in Oman. It considered as the primary source of income for about 20000 families. According to agriculture census (MAFWR, 2013), there are 166610 total agriculture holdings with a total cultivated area of 69000 ha. The main crops grown in the country are fruits, vegetables, field crops and perennial forage crops (Table 1.1). The main fruit crops grown in Oman are date palm, mango, lemon, banana and they consist about 45% of the total fruits cropping area in the country (MAFWR, 2013). Nineteen percent of the total crops grown in the country are vegetables and the vegetable areas are increasing annually due to the local and exotic demand in the region. The reports showed a doubling of the total vegetable area from 6000 ha in 2012 to 13000ha in 2014 (MAFWR, 2014).

Table 1.1 Estimates of cropping area (ha) and production (tonnes) in Oman in 2014 (MAFWR, 2014).

Crop	Total area (ha)	Total production (tonnes)	Area Percentage %
Fruits	30846	404400	45
Vegetables	13106	334581	19
Field crops	4843	22230	7
Forage crops	20068	753600	29
Total	68863	1514811	100

The temperature degrees in winter time which varies between 15 and 30 ˚C favour the reproduction of pests and diseases which forces the local farmers to increase the use of pesticides. Farms in Oman are varied in terms of total cultivated area. The majority of farms are small in scale (0.4ha) but some farms may reach 84 ha and above (OSS, 2012). The main reasons are the lack of irrigation water, climatic conditions and especially the elevated temperatures throughout the year, low marketing demand, salinity, pests and diseases, labour power availability and inheritance reasons (Omezzine and Zaibet, 1998). The Ministry of Agriculture and Fisheries and Water Resources (MAFWR) reports (unpublished) showed that about 82 new greenhouses were established in 2015 under the Ministry's partial subsidiary programmes to the small-scale farmers which increased the cultivation of some vegetables such as cucumber in the greenhouses subsidised by the Ministry. However, in the last decades, the number of large scale (commercial) farms also increased due to the increase in demand from neighbouring countries for vegetable crops such as bean, carrot, tomato, eggplant and cucumber.

Figure 1.1 Map of Oman showing the eleven regions (mapsofworld.com, 2017).

1.1 Water resources for agriculture in Oman

The annual rainfall in Oman is 100 to 200mm (Norman, et al, 1998) which forces farmers to depend on ground water to irrigate their farms. The underground water flows gradually through water channels called "Falaj" singular and "Aflaj" plural (Figure 1.2), to irrigate fruit trees mainly date palms and other fruit trees such as lemon, banana, fig and guava. It was reported that there are more than 128,000 wells tapping the major aquifers and around 4,100 different types of Aflaj, 3,095 of which originate from the groundwater (Jamrah et al., 2008). Flood irrigation has been used to irrigate date palm trees for hundreds of years but due to small amounts of rainfall, ground water levels have reduced to minimum levels.

Figure 1.2 Falaj irrigation system used to irrigate fruit trees in Oman (The photo was taken by the researcher, 2021).

Unlike fruit trees, irrigation of vegetable crops has been achieved by pumping underground water by means of petrol or kerosene pumps in the past. For the farms that have access to an electricity supply, the farmers have started using electrical water pumps which can extract the water from depths and these pumps are more efficient in distributing water for larger scale areas more evenly and simultaneously. For vegetable crops, drip irrigation has shown better performance than sprinkler irrigation (Al Said et al., 2012). The most challenging water-related constraints for agriculture in Oman are drought and the provision of pure irrigation water throughout the planting year. Salinity in the areas close to the sea is degrading and reducing the amount of arable land in especially in Al Batinah South and North governates (Al-Jabri et al, 2015 and Deadman et al., 2016). The government has issued many regulations in order to save underground water and reduce saline encroachment (Ishaq et al., 2105). These regulations include reducing the expansion of grass and fodder plantations since these crops demand a lot of water.

1.2 Vegetable production in Oman

There are many factors affecting crop production in Oman. Climatic conditions played a vital role in this matter due to elevated temperatures throughout the year. Vegetable production thrives at relatively short winter time starting in October and ending by end of March. Although the climatic conditions and lack of water are the main challenges, vegetable cultivated area increased using greenhouses and growing under shades for some crops such as sweet pepper. For instance, in A’Suwaiq Wilaya, the total vegetable crops area increased from 1139 ha to 6182 ha with between 2004–2005 and 2012–2013 (Al-Aufi et al., 2019). However, the latest report issued in 2017 by the Ministry of Agriculture and Fisheries and Water Resources showing that the total area of vegetables in Oman increased from 21044 ha to 21448 ha between 2015 and 2017 and the production of vegetables increased from 770 tons to about 815 tons in the same period. Tomato, pepper, eggplant and melon are in the top ten in terms of cropping area and production. Tomato comes on the top of the vegetable crops in area and production. According to MAFWR statistics (2017), the tomato area consists of 11% of the total cultivated area of vegetables and tomato production constitutes 24% of the total vegetable production. This reflects the high local and export demand for tomatoes for direct human consumption and for processing into products such as tomato ketchup, paste and other types of products.

1.3 Farm management and manpower

The report issued by the National Centre of Statistics (NCSI, 2020) showed that the numbers of Omani nationals working in the agriculture, forestry and fishing in 2019 was 1228 persons in comparison to 61250 expatriates. Expatriate labourers working in farms are mainly from Bangladesh, Pakistan and India (AL Zadjali et al, 2009) getting low income in comparison to the non-agricultural government sector (Kotagama and Al-Farsi, 2019). However, it has been suggested that the low-skilled agriculture labourers in Oman play a significant factor contributing to the deterioration of natural resources, particularly soil and water, through extensive use of agrochemicals and irrigation water (Al Zadjali et al, 2009). In the past, Esechie and Ibitayo (2011) reported that Indians were the majority of workforce (37.8%) in farms in Al Batinah governorates but more recently Al Zadjali et al. (2014) found that Bangladeshi workers had become the largest community in farms (84.5%). They ascribed the shift in the balance of nationalities of farm workers to changes in the policy of recruiting farm labour by farm owners which was affected by wages levels. According to Al Zadjali (2009), many farm labourers in Oman are illegal immigrants and low skilled. He also suggested that farm vacancies are frequently filled by those who have friends or relatives already in employment in Oman. It was demonstrated that educational status of farm workers was lower on nFA farms than on FA farms and the education levels of FA farm owners were higher than nFA farms owners (Esechie and Ibitayo, 2011 and Al Zadjali et al., 2014). Although there is a dearth in the reports or research on the decision-making process on crop protection issues within farm boundaries, Al Zadjali et al. (2014) indicated that farm owners of FA were more directly involved in decision-making with respect to pesticide applications whereas none of the nFA workers indicated any involvement of farm owners in such decisions and instead pesticide sellers and their friends were the main sources of information. This study aimed to explore the involvement of FA and nFA farm owners, tenants, foremen and workers in the decision-making process in crop protection issues and to try to understand the extent to which their decisions affect proper pesticide practices.

1.4 Crop protection

Oman is located in an arid climate and the temperatures rise in most agriculture areas dramatically in summer to reach 48°C compared to around 25°C in winter (Choudri et al., 2013). Elevated temperatures in summer produce wind turbulence which leads to accumulation of dust on the vegetable crops leaves which can attract different sucking insects such as mites, thrips, aphids and others. In addition, diseases such as wilts and rots that are caused by *Ceratocystis, Fusarium* and *Cladosporium* cause crop losses to the farmers (Al Raisi et al., 2011 and Al Sadi et al., 2015). On the other hand, the lower temperatures in winter lead to emergence of other insects such as spodopteran and weevils and diseases such as leaf spot and blights. These problems require a rapid control strategy to avoid crop losses. Although MAFWR provides free extension services and free crop production inputs through the Agriculture Development Directorate and centres scattered all over the country, there is still a lack of good crop protection advice, which may encourage farmers to search for other support services elsewhere. Crop protection programmes can be divided into two types: the government crop protection programmes and private ones. Government programmes are implemented for pests and diseases spread over a wide area causing huge losses not only to the farmers but also to the country as a whole. Private programmes are implemented by the farmers with support of private companies and pesticide retailers and these especially focus on vegetable crops.

1.4.1 MAFWR crop protection programmes

Programmes that are implemented by the MAFWR are basically for widespread problems such as dubas bug and red palm weevil on date palm trees, locusts, mango decline disease. They also promote adoption of integrated pest and disease management on vegetables. All these protection programmes are implemented legally based on agriculture law issued by royal decree no. 48/2006. Section four of the law was titled “Plant Protection and Pest Control” and articles 17 - 21 authorise MAFWR officials to enter any agricultural land and implement the necessary control actions in case of any pest and disease threats to the agriculture wealth in the country. MAFWR executes the main agriculture protection programmes in collaboration with other governmental bodies to ensure better execution and successful outcomes.

1.4.2 Private farms crop protection perceptions

The crop protection scenario in private vegetable production farms is quite different. In the past, MAFWR was supporting all farmers to overcome crop protection problems including diagnosis of pest and disease problems, suggesting better control strategies and subsidising the farmers with the materials required to perform the work. More recently, MAFWR stopped providing these free services due to economic constraints, making farmers shift to private companies and retailers to get advice on the diagnosis of different pest and diseases and recommending the chemicals they need use. In this process, MAFWR do not have any responsibilities but retailers implement a vital role. The farmers select and implement control measures based on the advice of these private companies and retailers. One question addressed in this thesis is: how reliable is the advice the farmers are receiving since there has never been any independent evaluation of the advisory process.

1.5 Pesticide application

1.5.1 Global overview

Although there are many crop protection strategies, pesticides are still considered as the most frequently used. Pesticide active ingredients with a knock-down action on insect pests are attractive to farmers who want to stop a serious infestation developing in order to avoid losing the crop and making a financial loss. There are many factors that may contribute to the increased use of pesticides worldwide. Farmer’s education level, experience, poor awareness of IPM programmes, ignorance of health and safety issues and government policies are all factors that may be involved in the quantity and methods of pesticide applications. The Food and Agriculture Organisation (FAO, 2018) reported that worldwide average use of pesticides per unit area of cropland has shown a gradual increase in the amount of pesticides used from 1.5 kg/ha to 2.63 kg/ha – a 57% increase - between 1990 and 2017 (Figure 1.3).

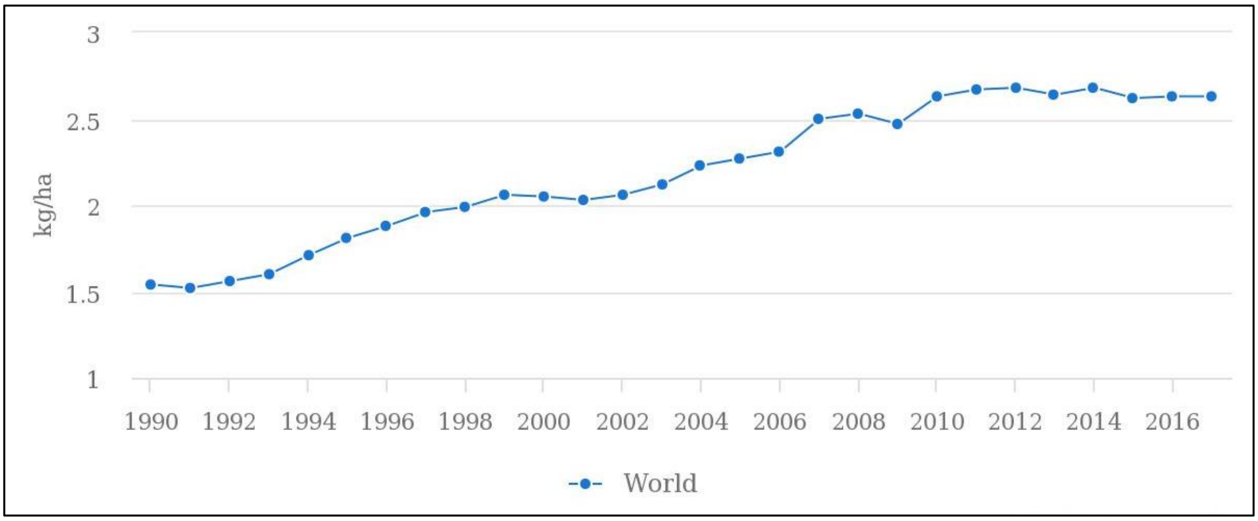

Figure 1.3 Worldwide average uses of pesticides per hectare of cropland between 1990 and 2017 (FAO, 2018).

1.5.2 Pesticide usage in Oman

Pesticides have also become one of the most important agriculture inputs in Oman in the last two decades such that pesticide application is the only crop protection strategy used by the majority of farmers in the country. The spread of different pest and diseases due to favourable climatic conditions and the lack of integrated pest management strategy within farms has increased the dependence in pesticide application as a sole control strategy which has led to an increase in the importation and use of pesticides. According to the reports issued by MAFWR[1], the pesticide importation over ten years reached a peak in 2017 of 1197 tonnes and then dropped to 432 tonnes in 2019 (Table 1.2).

[1] In an email to the author, Hanan Al Zakwani (MAFWR) acknowledged for the provision of information.
[1] Hanan Al Zakwani, personal communication, 24 January 2021.

Table 1.2 Amounts of pesticides (tonnes) imported to Oman between 2010 and 2019. [1]

	Quantity of pesticides (tonnes)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Insecticide	222	286	277	487	578	338	305	599	437	255
Fungicide	93	177	164	-	175	162	171	258	50	138
Herbicide	-	17	19	39	3	27	3	8	9	7
Rodenticide	-	28	59	15	12	33	56	52	50	8
Nematicide	-	-	183	-	-	-	-	5	8	8
Others	10	14	18	9	-	6	30	275	36	16
Total	325	522	720	550	768	566	565	1197	590	432

1.6 Pesticide retailers: Oman context

Pesticide retailers are the pesticide distributors or sellers. Globally, pesticide sellers play a vital role in pesticide handling and use especially in rural communities. For instance, in Bangladesh, pesticide sellers were found to increase the farmers' awareness of the need to use personal protective equipment more than government extension workers (Alam and Wolf, 2013). Sometimes however, pesticide sellers handle pesticides unsafely. For example, in Ghana, most pesticide sellers were found to store used and unused pesticides with food, display products in hot and sunny conditions, fail to wear personal protective equipment and did not wash after handling pesticides (Aidoo et al., 2019). By contrast, in Thailand, farmers were expecting more information and help from pesticide sellers on matters such as pesticide properties, diagnosis of crop problems and appropriate pesticide selection and on how to handle the products safely in order to minimise the pesticide's potential risks to humans and the environment (Khetwichan and Sirisunyaluck, 2015).

In Oman, some of retailers are importing and distributing pesticides while others are buying pesticides from local markets and reselling them to the farmers[2]. The total numbers of licensed pesticide retailers increased from 23 in 2015 to 152 by the end of 2020 (Table 1.3). In addition, the importing licences increased from 12 in 2016 to 76 compared to only two manufacturing licences (Table 1.3). The increase in the number of retailers could account for the expansion of pesticide sales in Oman and highlights the importance of these retailers in crop protection process. Imported and manufactured pesticides need to be registered first with the MAFWR before they can legally be sold while those who obtain pesticides from local markets do not need to register the products since these products should already be registered. Most of the retailers are expatriates and they therefore have different educational backgrounds and experience. There are, however, no reports or published literature available that could provide information about retailers in Oman and their roles in agricultural practices. However, informal observations and enquiries indicate that retailers are playing a vital role in agriculture and they are quite close to the farmers, especially to those who are of the same nationality. The farmers, therefore, are not only buying pesticides from retailers but also getting advice on pest and disease diagnosis and on pesticide selection and application. The quality of that advice depends on the retailer's education, experience and commitment to business ethics. In India, it was reported that there is a lack of knowledge or training on how to manage the people involved in the agriculture and fisheries (Raj and Kothai, 2014). Some retailers may mislead the farmers who have less education or who have little experience and knowledge on pest and disease diagnosis, pesticide selection including mixtures and their application including the number of treatments and dilution rate required, pre-harvest intervals in addition to health and safety measures required. Good advice is necessary as the farmers may not be able to read or understand the label instructions. The lack of monitoring and training programmes for retailers may aggravate these problems which, in the end, may lead to many negative complications for human health and the environment, not to mention the financial losses to farmers. However, although there were some indications of pesticide sellers' involvement in farmers' attitudes towards pesticide application (Al Zadjali et

[2] In a phone contact to the author, Nouh Al Hinai (MAFWR) acknowledged for the provision of information.
[2] Nouh Al Hinai, personal communication, 28 March 2021.

al., 2014), more studies are required to understand the extent to which pesticide sellers influence the perceptions and practices of farmers in pesticide use and handling. In the research described in this thesis, the investigations include a survey of pesticide retailers' ability (1) to identify the main crop protection problems of vegetable crops in Oman, (2) to recommend appropriate pesticides, dose rates, and pre-harvest intervals (PHI) and (3) to advise on the health and safety measures required in order to minimise adverse impacts on humans and the environment.

Table 1.3 The total numbers of pesticide retailing, importing and manufacturing licenses issued by MAFWR between 2015 and 2020.[2]

Year of issue	Pesticide retailers	Pesticide importers	Pesticide manufacturers
2015	23	0	0
2016	9	12	0
2017	24	10	2
2018	33	29	0
2019	20	5	0
2020	43	20	0
Total	152	76	2

2. Farmers' Associations (Benefits and constraints)

2.1 Benefits of farmers' associations

The non-governmental organisations (NGOs) such as farmers' associations/cooperatives may help their members to adopt improved agricultural practices and increase their productivity and income. Using the cooperatives' market share as a success indicator, the average market share for agricultural produce by agricultural cooperatives in the EU was 40% in 2012 albeit with considerable differences between member states due to differences in the policy, organisation and strategy between EU countries (Bijman and Iliopoulos, 2014). However, there are many reports showing positive trends of farmers' associations' benefits to their members. For example, membership of farmers' cooperatives in Ethiopia was reported to have a positive impact on the members' incomes, productivity, marketing of produce surpluses and household money savings in comparison to non-members (Debela and Diriba, 2018). Similar findings were demonstrated in France where a farmers' association was found to enable members to improve their production practices, plan quantities, share transport and centralize their orders and invoices (Noireaux and Edzengte, 2020).

In South Africa, Ortmann and King (2007) revealed that cooperatives were most effective and successful if the decision makers tackled the main factors related to the members and leader's knowledge, business skills and social services. Although these authors addressed the main benefit by showing how cooperatives were successfully achieving wider marketing opportunities for their members, the current land tenure system in South Africa prevented any sort of formal land ownership thereby reducing the incentive for local farmers to participate and benefit from the enhanced marketing opportunities. In India, Desai and Joshi (2014) found that the beneficial impact of belonging to a farmers' cooperative was heterogeneous. Their study involving 1474 women from 42 villages from four districts in Gujarat state, evaluated the influence of organising female farmers into producer associations. They reported that the programme weakly increased members' non-farm income and access to output markets, but that it had stronger impacts on members' awareness and utilisation of financial services. Interestingly, these benefits were associated with socio-economic conditions of self-employed women's association (SEWA) and non-

SEWA members. Specifically, although it was clear that a short-term programme (women farmers with global potential initiative) had slightly improved the incomes and outputs of poorer, less educated and landless women, neither the initiative nor the recommendations tackled these socio-economic constraints to their benefitting from SEWA.

Farmers' cooperatives are not only established to tackle the economic and financial issues, but they may also help farmers with various issues relating to crop protection and pesticide use. For instance, in China, Jin et al. (2015) found that members of a farmer cooperative adhered more closely to the proper use of pesticides than non-members. However, since the retailers rather than the cooperative were the main source of advice on pesticide application to almost 90% of the farmers, it is interesting that the authors did not assess whether the advice being provided by the retailers was appropriate or correct. In addition, only one cooperative farmers' group was studied, so that the results obtained may not reflect the ways in which other farmers' cooperatives are involved in the pesticide application practices.

2.2 Farmers' associations' constraints

Farmers' groups vary in how successful they are in disseminating information and technologies to small-scale farmers. Factors influencing their success include the extent of active member participation, mutual trust within the group, homogeneity of members, group capacity, number of linkages and type of group (Davis et al., 2004).
The success of such groups in attracting farmers to join may be influenced by factors such as education level, age, gender, benefits and training. For instance, lack of resources, unity and cooperation between organisations were found to be obstacles hindering the activity of the groups in Poland (Milczarek-Andrzejewska and Spiewak, 2018). Although there were significant differences in age, years of membership and relationships among group members, it was unclear how these characteristics of each group of farmers (farmers' trade union and branch organisation) influenced the effectiveness of the groups or their willingness to join a group.
The willingness of farmers to join associations/cooperatives may affected by many factors. For example, participation in farmers' associations and cooperatives

increased with the educational attainment of small-scale farmers in Vietnam (Vu and Le, 2020). Although farmers' associations have been found to be helpful for farmers in many cases, the management structure within a farmers' association may be influenced by favouritism instead of merit, which may affect the strength and sustainability of the association (Mhlanga-Ndlovu and Nhamo, 2017).

Overall, the heterogeneous impacts of farmers' associations/cooperatives on their members' perceptions and practices revealed different advantages and disadvantages which, in turn, were affected by different factors. The success of the farmers' cooperatives differs from one country to another due to different circumstances and factors affecting their success or failure. Although some obstacles to their effectiveness have been reported in some countries, still many cooperatives worldwide were able to provide significant benefits to their members. This observation is also true in Oman where the local farmers' association members share information that was found to have improved their farming practices in many aspects (Al Zadjali et al., 2014).

2.3 Farmers' associations (Oman context)

In Oman, the Farmers' Association (FA) was established in 2006 and announced officially on 12 October 2009 by a Ministerial decree no. 126/2009. On 21 December 2016, the name and scope of the activities of the association was changed by the Ministry of Social Development to the Omani Agriculture Association. The aim of this decision was to gather all the farmers across the country in one association. Since the decision was made, the Association opened many branches in Al Batinah, Al Dakhiliyah, Al Sharqyiah south and north, Al Dahirah and Dhofar regions. Some more branches are expected to open in the rest of the country. The total number of the association members increased to 270 farmers after the decision to merge the associations into one. This change will give the farming community a collective and stronger voice to put forward their demands and give a common platform to share experiences and benefits to develop the sector in a better way especially in the marketing issues where the farmers are mainly suffering from especially in the production season. One of main objectives of this association is[3]:

- Encourage and support the farmers to use environmentally-friendly pesticides and reduce the use of chemical products that may cause harm to humans and the environment.

It was reported that farmers within cooperatives are more likely to have a positive attitude towards a modern technology (Al-Anbari, 2016). Based on the effort being executed by the association in terms of encouraging the farmers to introduce new farming technologies and reduce the use of chemical agrochemicals, the association succeeded in increasing the number of greenhouses to 3000 and expanded the shade houses to 420ha. In addition, the FA succeeded in the management of 6300ha of cultivated land which strengthened the productivity and financial situation of the members towards more farming development. The majority of the FA products are exported to neighbouring countries. However, the labour law is one of the major constraints on further expansion. The Ministry of Labour is only allowing one immigrant labourer for every five cultivated acres (2.1ha) (Kotagama and Al Farsi, 2019). This number is not enough for vegetable crops since most of the farmers are using labour-intensive or manual methods for practices such as ploughing, weeding, pesticide application, harvesting and packaging (Figure 1.4).

[3] In an email to the author, Sa’ed Al Kharusi (Chairman of FA) acknowledged for the provision of information.
[3] Sa’ed Al Kharusi, personal communication, 6 January 2021.

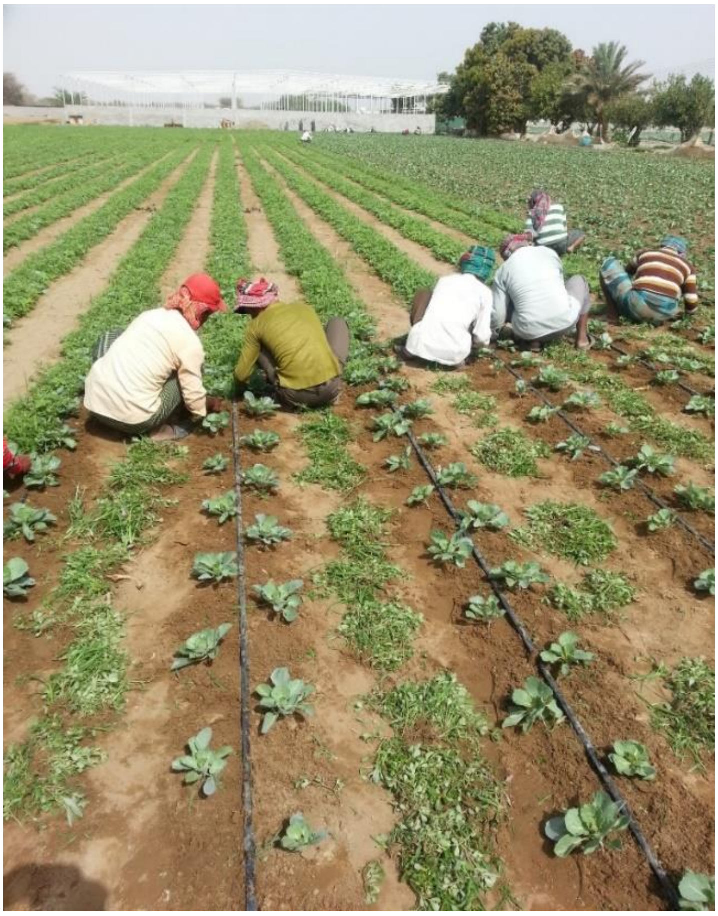

Figure 1.4 Manual weeding process in FA vegetable farms costs a lot of money leading to the need to introduce new technologies to reduce production cost (Photo taken by the researcher, 2016).

The FA members are mainly producing vegetables such as tomato, eggplant, cucumber, sweet pepper, squash, melon and others. They also produce high quality beans under contract mainly for exporting to Japan and some EU countries. The situation in non-FA farms is quite different in terms of land size, education, experience, knowledge diffusion and farming practices. Although the pesticide applicators, such as workers, within FA farms are basically expatriates, still the actual FA members are guiding and instructing the applicators on how to apply the pesticides. According to (Al Zadjali et al., 2014), workers and owners of FA farms were better educated than respondents from non FA farms. This better education associated with the FA along with direct supervision by the farm's owner could help in making pesticide application safer and more effective. This educational development and training is supported by interactions with the local and expatriate experts who visit the association from time to time leading to better knowledge diffusion amongst FA members especially in the technical farming practices (Al Zadjali et al., 2013). In this research, the competency of FA and nFA respondents are compared in their ability to diagnose the main vegetable pests and diseases, to select appropriate pesticides, to choose correct dose rates and PHIs and suitable health and safety measures. The findings of the study will provide a clearer picture of the role of FA, as a non-governmental association, in gathering many farmers together for the purpose of sharing information on better crop protection practices.

3. Research justification, objectives and questions

The previous research in Oman (Al Zadjali et al., 2014) identified routes by which knowledge diffuses through the farming community. The research identified that the FA in Al-Batinah appeared to be an effective conduit for the diffusion of knowledge about pesticide legislation and general awareness. This research left some questions about pesticide use unanswered and these have been investigated in this research. This includes the accuracy of pest and disease diagnoses, proper pesticide selection, accuracy of pesticide preparation and usage, and the risks and health and safety precautions associated with pesticide application. Although the previous research gave some answers to these questions, a number of key issues remain unanswered. Al Zadjali's research appears to indicate significant differences in approach to pesticide usage and the adoption of safety practices between FA and nFA farms. Thus, a study sample for the research could include two categories of farms: FA farms and nFA farms. These are all vegetable growers where the pesticide applications are the dominant control strategy among the farmers for their many pest and disease problems. This approach is very important since it could help to design a framework for agriculture and sustainable pesticide use in the future.

The research is therefore addressed to focus on the following objectives:

1. To evaluate the ability of the farmers to diagnose common economically important insect pests and diseases of some vegetable crops in Oman.
2. To ascertain the appropriateness of pesticide selection and understand the possible factors affecting these decisions and evidence for the development of resistance to pesticides due to their repeated and excessive use.
3. To investigate
   - the appropriateness of pesticide application in relation to the farmer's education, experience and training and, linked to that,
   - the uniformity and accuracy of pesticide application in the field.
4. To examine the awareness amongst farmers on the potential adverse effects of pesticides to human beings and the environment.
5. To investigate the pesticide retailers' perceptions and knowledge on pest and disease diagnosis, proper pesticide selection and application and health and safety measures.

In order to meet these objectives, two farm-based surveys were carried out, one with FA farmers and the second with nFA farmers. A survey of retailers was also administered. To triangulate results of these surveys and fulfil the second part of the third objective, field experiments were designed to measure the average actual application rates in five fields and, within three fields, the spatial variability of pesticide application.

4. Hypotheses

Hypothesis 1: FA members identify pests and diseases more accurately than non-FA members.

Previous studies showed that identification of causal agents of serious and economic pest and diseases worldwide plays a vital role in the implementation of successful control measures. For example, (Ebregt et al., 2004) found that the increase in sweet potato production in Uganda depend on farmers' knowledge of the causal agents responsible for decreased yield and the selection of appropriate disease control measures to mitigate the problem. Identification of pests and diseases requires experience and knowledge, and this could reflect the abuse of pesticide application in developing countries where the farmers may be illiterate or lack training in crop protection. Incorrect diagnoses will usually lead to wrong pesticide selection and application. In Oman, the ability of FA and nFA farmers to diagnose various pests and diseases attacking their vegetable crops were not studied.

In the farm-based surveys, the ability of farmers to identify eleven major pests and diseases of the main vegetable crops was investigated (Chapter 3). The farmers' attitudes towards their capability to diagnose the different pests and diseases that attack their crops and the factors affecting their ability were explored. In this way, training requirements for the more sustainable use of pesticides in Oman may be identified.

Hypothesis 2: FA members are more likely to select an appropriate active ingredient and to apply pesticides correctly than non-FA members.

Selection of the proper pesticide(s) to control pests and diseases is considered as the second step in management strategy. The successful or the proper selection of an active ingredient could save money, time and effort to the farmers. In addition, it would definitely help in minimising adverse impacts on the crop plant, humans and the environment. Farmers are expected to differ in their ability to select the proper active ingredient to be used for a specific problem and this may depend on the person or company that giving advice. Educated and experienced farmers should be able to select the proper active ingredients for the regularly occurring pests and diseases on their crops. This research has tried to approach the farmers' attitudes, knowledge and perceptions in pesticide selection and application, finding out the decision-making pathway among vegetable growers and what are the potential factors leading their selection and application (Chapter 4).

Two subsidiary hypotheses relate to the field measurements:

1) Farmers do not target the label recommended rates when applying pesticides; and

2) The use of high-pressure sprayers on both FA and nFA farms leads to spatial variability of pesticide applications such that significant areas receive pesticide applications deviating by more than 10% from the target.

Hypothesis 3: The FA members are more aware than nFA members of the health and safety measures required when handling pesticides.

The use of pesticides has increased worldwide in different patterns influenced by many factors such as farmer's education, experience, access to extension services, pesticide prices, retailers, legalisation enforcements and training. Although pesticides have become one of the major farming inputs, few farmers may understand the potential adverse effects of these products to humans and the environment. This problem is easily noticed in developing countries where the pesticide applicators can be observed spraying pesticides without using personal protection equipment (PPE) (Damalas and Hashemi, 2010). There are many reports showing that the exposure of humans working in agriculture to pesticides has resulted in poisoning symptoms and fatalities among pesticide workers (Tsimbiri et al., 2015 and Fan et al., 2015).

In order to test this hypothesis, FA and nFA farmers' knowledge, insights and implementation of the label instructions were investigated. In addition, the perceptions among these two groups in regards to health and safety measures and deployment of PPE to ensure safety of pesticide applicators, were explored (Chapter 5).

Hypothesis 4: Retailers vary in their ability to diagnose pests and diseases, to recommend appropriate pesticides and application procedures and to recognise the adverse effects of pesticides on humans and environment.

Farmers ask retailers for information and advice on pest and disease diagnosis, pesticide selection and application and on health and safety measures. They were therefore included in the survey work to elucidate the quality of the advice that they might provide, which in turn could affect farmers' practices in relation to pesticide use.

In the retailers' survey, the ability of retailers to identify eleven major pest and diseases of the main vegetable crops grown in farms was tested together with their knowledge of appropriate pesticides for control (Chapter 6). The links between their knowledge and their education levels, experience, training and other factors was explored to understand how the quality of the advice they offer to farmers might be improved (Chapter 6).

In general, the goal of the research was to compare vegetable farmers in Oman who were members of the Omani Farmer Association (FA) with others who were not members of this or any other association (nFA). The comparison between these two groups includes their perceptions and practices on the pests and diseases of vegetable crops, proper pesticides selection and application and health and safety measures. Since pesticides seller found to play a key role in farmers decision, the study also included pesticides retailers' perception and practices for their knowledge, practices and skillsets on the same field of research that being studied for farmers.

The results of the study are written as four papers in chapters 3-6. To clarify the methodology, aspects of which are common to more than one chapter, a short account of the methodology is given in chapter 2 which was thesis has four main chapters. In Chapter 3, the farmers' ability to identify major pests and diseases is explored while their knowledge, attitudes and practices when selecting and applying pesticides for these problems are reported in Chapter 4. Chapter 5 investigates of health and safety awareness and measures adopted when using pesticides. Given their expected importance in providing advice to farmers, chapter 6 assesses the ability of pesticides retailers to identify pests and diseases, recommend pesticides and advise on their application and their perceptions on pesticide health and safety measures. The main objectives, hypotheses and research questions for each chapter are summarized in table 1.4. Finally, Chapter 7 comprises a general discussion and makes recommendations for improving the use of pesticides among vegetable farmers in Oman.

Note that chapters 3-6 are written for potential publication and so each contains a summary and a list of references resulting in a degree of repetition.

Table 1.4 Summary of the thesis chapters, objectives, hypothesis and research questions

Chapter number and title	Objective	Hypothesis	Research question
3. Factors affecting farmers' ability to identify major pests and diseases of some vegetable crops.	To evaluate the ability of the farmers to diagnose common economically important insect pests and diseases of some vegetable crops in Oman.	FA members identify pests and diseases more accurately than nFA members.	Can farmers diagnose the common pests and diseases of the vegetable crops they are growing and what factors affect their ability to identify the problems?
4. Farmers' knowledge, attitudes And practices when selecting and Applying pesticides to some Vegetable crops in Oman.	1. To ascertain the appropriateness of pesticide selection and understand the possible factors affecting these decisions and 2. To investigate the appropriateness of pesticide application in relation to the farmer's education, experience and training and, linked to that, the uniformity and accuracy of pesticide application in the field.	FA members are more likely to select an appropriate active ingredient and to apply pesticides correctly than nFA members.	Can FA and nFA farmers select the appropriate pesticides and do they apply them according to the labels' recommendations?

Table 1.4: Continued

5. Knowledge, perceptions and practices of health and safety measures for pesticides amongst vegetable farmers in Oman.	To examine the awareness Amongst farmers on the potential adverse effects of pesticides to human beings and the environment.	The FA members are more aware than nFA members of the health and safety measures required when handling pesticides.	Are the farmers aware about the potential adverse effects of pesticides on humans and the environment?
6. Assessment of pesticides retailers' ability to identify pests and diseases, proper pesticide selection and application and their perceptions on pesticide health and safety measures.	To investigate the pesticide retailers' perceptions and knowledge on pest and disease diagnosis, proper pesticide selection and application and health and safety measures.	Retailers vary in their ability to diagnose pests and diseases, to recommend Appropriate pesticides and Application procedures and to recognise the adverse effects of pesticides on humans and environment	Can pesticide retailers diagnose the common pests and diseases of the vegetable crops, select the proper pesticides and recommend the proper application rates and PHI and are they aware of the potential risks associated with pesticides?

6. References

Aidoo, A. K., Arthur, S., Bolfrey – Arku, G. and Mochiah, M. B. (2019) 'Pesticides abuse and health implications in Ghana: A review', *International Journal of Environment, Agriculture and Biotechnology*, 4, pp. 874-883.

Alam, S. A. and Wolff, H. (2013) 'Do pesticide sellers make farmers sick? Health, information, and adoption of technology in Bangladesh', *Journal of Agricultural and Resource Economics*, 41. pp. 62-80.

Al Aufi, K., Al Wardy, M., Choudri, B. S. and Ahmed, M. (2019) 'Analysis of crops cultivation trend: A shifting scenario in a coastal Wilayat, Oman', *Environment, Development and Sustainability*, 22, pp. 2685-2698.

Al Anbari, J. S. K. (2016) 'Understanding constraints to the development of the agricultural sector in Oman: An application of the Theory of Planned Behaviour', (PhD Thesis) UK: The University of Reading, pp.165.

Al Jabri, S. A., Ahmed, M. and Choudri, B. C. (2015) 'Prospects of desalination for irrigation water in the Sultanate of Oman', *Journal of Water Reuse and Desalination, 5, pp. 430-436.*

Al Raisi, Y. M., B'Chir, M. M., Al Mandhari, A. M., Deadman, M. L. and Gowen, S. R. (2011) 'First report of *Ceratocystis radicicola* associated with date palm disease in Oman', *New Disease Reports,* 23, pp. 23.

Al Sadi, A. M., Al Jabri, A. H., Al Mazroui, S. S. and Al Mahmooli, I. H. (2012) 'Characterization and pathogenicity of fungi and oomycetes associated with root diseases of date palms in Oman', *Crop Protection*, 37, pp. 1-6.

Al Sadi, A. M., Al Said, F. A., Al Kaabi, S. M., Al Quraini, S. M., Al Mazroui, S. S., Al Mahmooli, I. H. and Deadman, M. L. (2011) 'Occurrence, characterization and management of fruit rot of immature cucumbers under greenhouse conditions in Oman, *Phytopathologia Mediterranea,* 50, pp. 421-429.

Al Said, F. A., Ashfaq, M., Al Bahri, M., Hanjra, M. A. and Khan, I. A. (2012) 'Water productivity of vegetables under modern irrigation methods in Oman', *Irrigation and Drainage*, 61, pp. 477-489.

Al Zadjali, K. M. S. (2009) 'Management of agricultural resources in the Sultanate of Oman (Al-Batinah as case study)', PhD Thesis, The University of Reading, UK, pp.315.

Al Zadjali, S., Morse, S., Chenoweth, J. and Deadman, M. (2013) 'Disposal of pesticide waste from agricultural production in the Al-Batinah region of Northern Oman', *Science of the Total Environment*., 463–464, pp. 237-242.

Al Zadjali, S., Morse, S., Chenweth, J. and Deadman, M. (2014) 'Factors determining pesticide use practices by farmers in the Sultanate of Oman', *Science of the Total Environment*., 476-477, pp. 505-512.

Bijman, J. and Iliopoulos, C. (2014) ‘Farmers’ cooperatives in the EU: Policies, strategies and organization’, *Annals of Public and Cooperative Economics,* 85, pp. 497-508.

Bond, J. L., Kriesemer, S. K., Emborg, J. E., Chadha, M. L. (2007) ‘Understanding farmers’ pesticide use in Jharkhand India’, *Extension Farming Systems Journal*, 5, pp. 53-62.

Choudri, B. S., Al-Busaidi, A. and Ahmed, M. (2013). 'Climate change, vulnerability and adaptation experiences of farmers in Al-Suwayq Wilayat, Sultanate of Oman', *International Journal of Climate Change Strategies and Management*, 5, pp. 445-454.

Damalas, C. A. and Hashemi, S. M. (2010) ‘Pesticide risk perception and use of personal protective equipment among young and old cotton growers in northern Greece’, *Agrociencia*, 44, pp. 363-371.

Davis, K., Franzel, S. Hildeband, P., Irani, T. and Place, N. (2004) 'Extending technologies among small-scale farmers in Meru, Kenya: Ingredients for success in farmer groups', *The Journal of Agricultural Education and Extension*, 10, pp. 53-62.

Deadman, M. L., Al Sadi, A. M., Al Wardi, M. M., Al Kiyumi, K. S. M., Deadman, W. M. and Al Said, F. A. (2016) 'Spatio-temporal dynamics of land use changes in response to external pressures in Oman: Greenhouse cropping as an example', *Journal of Agricultural and Marine Sciences*, 21, pp. 33-46.

Debela, M. and Diriba, S. (2018) 'Impact of cooperatives membership on economy, in eastern Oromia: The case of Haramaya agricultural farmers' cooperative union (HAFCU)', *Annals of Public and Cooperative Economics,* 89, pp. 361-376.

Desai, R. M and Joshi S. (2014) 'Can producer associations improve rural livelihoods? Evidence from farmer centres in India', *Journal of Development Studies*, 50, pp. 64-80.

Ebregt, E., Struik, P. C., Abidin, P. E. and Odongo, B. (2004) ‘Farmers’ information on sweet potato production and millipede infestation in north-eastern Uganda. I. Associations between spatial and temporal crop diversity and the level of pest infestation’, *Wageningen Journal of Life Sciences*, 52, pp. 47-68.

Esechie, J. O. and, Ibitayo, O. O. (2011) 'Pesticide use and related health problems among greenhouse workers in Batinah Coastal Region of Oman', *Journal of Forensic and Legal Medicine*, 18, pp. 198-203.

Fan, L., Niu, H., Yang, X., Qin, W., Bento, C. P. M., Ritsema, C. J. and Geissen, V. (2015) ‘Factors affecting farmers’ behaviour in pesticide use: Insights from a field study in northern China’, *Science of the Total Environment*, 537, pp. 360-368.

FAO, (2018) 'Pesticide statistics', FAO Annual Report, 2018.

Hellin, J. (2012) 'Agricultural extension, collective action and innovation systems: Lessons on network brokering from Peru and Mexico', *Journal of Agricultural Education and Extension,* 18, pp. 141-159.

Information, National Centre for Statistics (2020) '*Statistics'*, *ncsi.gov.om/Pages/NCSI.aspx*. (Access on 15 February 2021).

Ishag, K. H. M. and Abdelaziz, H. H. (2015) 'Water policy under risk and uncertainty. A dynamic evaluation model of fodder cultivation in Oman', *Sustainable Agriculture Research*, 4, No. 1.

Jamrah, A., Al-Futaisi, A., Rajmohan, N. and Al-Yaroubi, S. (2008) 'Assessment of groundwater vulnerability in the coastal region of Oman using DRASTIC index method in GIS environment', *Environmental Monitoring and Assessment,* 147, pp. 125-138

Jin, S., Bluemling, B. and Mol, A. P. J. (2015) 'Information, trust and pesticide overuse: Interactions between retailers and cotton farmers in China', *Wageningen Journal of Life Sciences*, 72, pp. 23-32.

Khetwichan, P. and Sirisunyaluck, R. (2015) 'Farmers' needs for advise appropriate pesticide application from sellers in Roi Et province', *Journal of Agricultural Technology,* 11, pp. 1297-1307.

Kotagama, H. B. and Al-Farsi, H. (2019) 'Impact of the domestic labor market on sustainability of agriculture in Oman', *Journal of Agricultural and Marine Sciences*, 23, pp. 24-28.

MAFWR, (2013) 'Agricultural census report (Vol. 1)', Ministry of Agriculture and Fisheries and Water Resources, Oman, Muscat.

Mhlanga-Ndlovu, B. F. N. and Nhamo, G. (2017) 'An assessment of Swaziland sugarcane farmer associations' vulnerability to climate change', *Journal of Integrative Environmental Sciences*, 14, pp. 39-57.

Milczarek-Andrzejewska, D. and Spiewak, R. (2018) 'Farmers' associations: Their resources and channels of influence. Evidence from Poland', *Sociologia Ruralis*, 58, pp. 825-845.

Mubushar, M., Aldosari, F. O., Baig, M. B., Alotaibi, B. M. and Khan, A. (2019) 'Assessment of farmers on their knowledge regarding pesticide usage and biosafety', *Saudi Journal of Biological Sciences,* 26, pp. 1903-1910.

NCSI (2020) 'Statistical Year Book', Muscat.
Available at: https://www.ncsi.gov.om/Pages/NCSI.aspx (Accessed on 15 January 2021).

Noireaux, V. and Edzengte, J. E. (2020) 'The benefits of the digital supply chain for horizontal resource pooling - the case of the Bio Loire Ocean farmers' association. *Supply Chain Forum: An International Journal,* 21, pp.196-205.

Norman, W. R., Shayya, W. H., Al-Ghafri, A. S. (1998) 'Irrigation water costs and management practices among farms in Northern Oman', *Journal of Scientific Research, Agricultural Sciences*, 3, pp. 1-8.

Omezzine, A. and Zaibet, L. (1998) 'Management of modern irrigation systems in Oman: Allocative vs. irrigation efficiency', *Agricultural Water Management*, 37, pp. 99-107.

Ortmann, G. F. and King, R. P. (2007) 'Agricultural cooperatives II: Can they facilitate access of small-scale farmers in South Africa to input and product markets?', *Agrikon*, 46, pp. 219-244.

OSS. (2012) 'Oman salinity strategy report (OSS)', Ministry of Agriculture and Fisheries, Sultanate of Oman and International Centre for Biosaline Agriculture, Dubai, UAE.

Raj, A. B. V. and Kothai, P. S. (2014) 'Study on the impact of total quality management practices in the construction Industry', *The International Journal of Management*, 3, pp. 1-22.

Sharifzadeh, M. S., Abdollahzadeh, G., Damalas, C. A. and Rezaei, R. (2018) ‘Farmers’ criteria for pesticide selection and use in the pest control process’, *Agriculture (Switzerland)*, 8, pp. 1-16.

Tsimbiri, P. F., Moturi, W. N., Sawe, J., Henley, P. and Bend, J. R. (2015) ‘Health impact of pesticides on residents and horticultural workers in the lake naivasha region, Kenya’, *Occupational Diseases and Environmental Medicine*, 3, pp. 24-34.

Vu, H. V., Ho, H. and Le, Q. H. (2020) ‘Impact of farmers’ associations on household income: Evidence from tea farms in Vietnam’, *Economies*, 8, 92.

Chapter 2. General Materials and Methods.

2.1 Introduction

In this section, the methodology designed and used to address the research questions (Table 1.4) is described. Qualitative and quantitative data collection methods were included using the questionnaires, which were executed by face-to-face interviews. Since the postal service is seldom used in Oman by the farming community and internet access is limited, the only way to approach respondents was to visit them in person and gather the required information through a face-to-face session. The face-to-face survey is a personal interview approach that probes the answers from the respondents and can give the participants the chance to explain their answers in detail, so that researchers can understand and collect the needed feedback easily and directly. Although the questionnaire is a widely used and common method for researchers to collect information from respondents in different fields (Galletta, 2013 and Hesse-Biber, 2016), it is a time-consuming process for both the researcher and the respondent and so considerable thought needs to be given to the structuring of the questionnaire itself and pilot studies with a small number of farmers and retailers was administered to ensure the questions were appropriate and easily understood and that respondents would be able to provide the information needed.

In this research, the knowledge, attitudes and practices of vegetable farmers and pesticide retailers in relation to crop protection were assessed. The targeted respondents were scattered over a large area of the country. Thus, surveys using in-person interviews to complete questionnaires and, where appropriate, group discussion methods were used as they were the only way to obtain reliable quantitative and qualitative data from the respondents. Specifically, it was only by visiting and interviewing respondents personally and asking them questions directly with a complete guarantee of anonymity that many might be willing to provide valid and reliable answers. Other methods such as an online survey could not meet these requirements adequately and the respondents may be more inclined to finish faster with incomplete answers.

Moreover, in Oman, most of the farmers and retailers are expatriate, have a relatively low level of education and may not have access to the internet. Hence, they could not be reached through online questionnaire or any other methods. In addition, meeting farmers or respondents who speak other languages need to be taken in consideration to understand precisely their opinions, experiences and attitudes and this can be achieved through a wider personal discussion in many cases to grasp the complete information required. For example, non-Arabic and/or local names for crop protection problems could be accommodated through in person meetings and non-Arabic or English-speaking respondents could be reached. A further major advantage was possible that it was possible to triangulate some of the farmer's answers by visiting their pesticide stores and sometimes observing how they applied pesticides to their crops.

Taking in consideration the overall research outline, the selected research methods (in-person interview with a questionnaire and focus group) were the most suitable methods to achieve the main objectives of the research and answer the research questions.

The qualitative data collection consisted of four stages: stage one targeted respondents from farms aligned with the Farmers' Association (FA). In stage two, respondents from farms not aligned with the Association (nFA) were targeted. In stage three, pesticide retailers in the same wilaya as the FA and nFA farms were targeted. Stage four utilized a focus group where FA members were gathered and invited to discuss different issues related to pesticides based on their experiences.

Prior to the interview, all respondents were informed orally and in writing that their participation in the survey would remain anonymous. The identity, background of the researcher and the purpose of interview were explained to the respondents through a well-constructed document (Appendix 2.1). In addition, the contact details of researchers and supervisors were also provided in the same document to facilitate the participants and respondents in any future correspondence or if the respondent decided to withdraw from the survey at some time in the future. Ethical clearance was obtained from the University of Reading prior to administering the questionnaire (Appendix 2.2).

Since pesticides retailers or sellers play a major role in providing the guidance to farmers for various farming practices in Oman, the questionnaire administered to growers was modified slightly to create a retailers' questionnaire in order to probe the seller's perceptions and practices towards pesticides (see appendix 5.1).

Since the researcher is on the staff of the pesticide section of the Ministry of Agriculture, Fisheries and Water Resources in Oman (MAFWR), it was quite likely that he might be regarded as a government inspector by some farmers or retailers especially if he dressed in formal Omani clothing or arrived in a government vehicle. Some precautions were, therefore, taken to minimise respondents' hesitation from disclosing the true information needed to investigate their perceptions and practices. To achieve a suitable level of confidence, the researcher changed his traditional Omani clothing and used clothing associated with foreigners. He also used a privately-owned vehicle rather than official (government) vehicle when visiting farms. He introduced himself as a student belonging to a UK university who was visiting farms in the Sultanate of Oman for research purposes only. He also learnt some "Urdu" or "Bangladeshi" agriculture terms to facilitate his mission and explain the provisions taken to guarantee the anonymity of participating farmers. These precautions were taken to implement FA, nFA and retailers' surveys and they were found to be very helpful throughout the process of data collection.

In addition to farmers' and retailers' surveys, a group of FA farmers were gathered for a group discussion to assess their perceptions and practices on pesticide applications in the areas that have not being covered in the questionnaires. The total number of respondents participated in the research work are given in the Table 2.1. However, prior to the deployment of the questionnaires to farmers and retailers, pilot studies were conducted to test the robustness of the questions.

Table 2.1 The total number of respondents who participated in the farmers' surveys, group discussion and retailers' survey. The FA farmers who participated in the group discussion were part of the initial survey (activity 1).

No.	Research activity	Number of respondents	Date
1a	Pilot survey of farmer's questionnaire	3	March 2015
1b	Survey of farmers who were members of the Farmers' Association (FA)	40	April to May 2015
1c	Survey of farmers who were not FA members	120	November 2015 to February 2016
2	Group discussion with FA farmers	13	15 February 2017
3a	Pilot survey of retailer's questionnaire	2	February 2017
3b	Retailers' survey	75	March to July 2017

2.2 Pilot study of farmers' questionnaire

The pilot study was held in March 2015 in Samail Wilayat located in the Ad Dakhliyah governorate of the country. Three farms were selected outside the intended research area. Selection was based on the crops grown since the study focused on vegetable growers. As an outcome of the pilot study, many questions were modified. Most of the questions were revised, restructured and rearranged. The final draft included the name of the interviewer, the date of the interview and a unique participant number. Questions about the respondent in terms of his or her status on the farm, responsibility for pest and disease diagnoses and pesticide selection and application were included to ensure that the researcher was interviewing the person on the farm who had responsibility for making decisions about these particular issues. Questions were also added to document anecdotal evidence for lack of pesticide efficacy and the actions taken by farmers when they observe low efficacy. Different possible answers may indicate resistance development which should be investigated further in future research.

In the diagnosis section, the respondents were shown photos of different crop protection problems likely to occur on the vegetable crops they were growing. They were asked to identify them in order to check their capability to diagnose the problem. They were then asked to select appropriate pesticides to control the problem. After the pilot study, the binary answer choice of YES or NO was amended to include a DON'T KNOW option to provide a third choice for respondents who were unsure or doubtful about the name of the pest or disease. Since most of the respondents were likely to be expatriates from south/east Asia, there was a strong possibility that Arabic or English names might have caused additional confusion, so images of the problems were used. Local or other pest and disease names in their own language or even what to do to control the problem were all accepted as correct information. Demographic questions were used in the questionnaire to collect the basic information of the respondents such as age, education level and qualifications. Likert scale questions are easily deployed and are usually reliable for assessing attitudes or performances in different subject areas. The Likert scale method was used mainly in the Risk, Health and Safety part of the questionnaire where respondents were asked to provide answers using a five-point scale incorporating NEVER, RARELY, SOMETIMES, USUALLY, and ALWAYS.

2.3 Selection of participants

The FA farms were selected from the list of FA members provided by the chairman of the association, who provided their name, location and contact details. The respondents were selected based on crop grown so that only vegetable growers were targeted. The selected respondents were each contacted and briefed by the researcher on the purpose of the research. Those agreeing to participate were then visited and interviewed. Almost all FA farmers growing one or more of the relevant crops agreed to participate in the study.

The majority of vegetable farmers in Oman do not belong to the FA. Since, by definition, there is no association of nFA farmers and there is no database of their names, locations and contact details, selecting and interviewing these farmers was a serious challenge. The Agriculture Development Directorate of the Ministry of Agriculture, Fisheries and Water Resources (MAFWR) located in each wilaya provided some information allowing selection of some farmers based on the crops they grew. As far as possible however, the farmers were selected simply by walking and driving between the farms, observing the crops in their fields to ensure they were growing vegetables and asking the owner, foreman or tenant if he or she was interested to participate in the study. It should be noted that this was not a straightforward process. For example, although farm staff could see the researcher standing in front of the farm entrance and wanting to talk to them, many refused to respond or even allow access to the farm to the researcher.

Some nFA farms were in the same area as the FA respondents while others were not. The survey covered the seven major vegetable production governorates in Oman (Figure 3.1) and included Al Batinah north and south, Ash Sharqiyah north and south, Ad Dakhliyah, Adh Dhahirah and Al Buraimi.

2.4 Survey of FA farmers

The survey was carried out from April to May 2015 on vegetable farms in the Al Batinah south and north coastal areas of northern Oman (Figure 3.1). A total of forty FA vegetable growers participated. For every participant and prior to interview, an appointment was made for the researcher to meet the respondent at their farm at a mutually agreeable time and date to avoid interfering with their other activities. Each respondent was visited in person by the interviewer and the discussion lasted between half to one hour depending on the farmer’s knowledge and experience. The interviews were conducted in Arabic since all the FA members were Omani nationals with Arabic as their native language. In addition to completing the questionnaire, farmers were asked to show pesticides stored on the farm in order to investigate the type of pesticides they are using and to distinguish between proprietary and so called “me-too” products. However, for the stored pesticides at respondents’ farms (section 7 in the questionnaire), photos of the pesticides' labels were taken by mobile phone camera instead of writing information during the interview time to reduce interview time. Later, the data of each pesticide then extracted from the photos of the pesticide labels.

2.5 Survey of nFA farmers

A total of 120 nFA respondents were interviewed in the period from November 2015 to February 2016. The interviews were therefore conducted during the main vegetable growing season (i.e. from September to March when temperatures are lower). The interviews were held face-to-face at the respondents' farms and the time for each interview varied from half an hour to an hour depending on the knowledge and experience of the respondents. The questionnaire was the same as for the FA respondents, but because of the ethnic diversity of nFA respondents, the languages used included Arabic and English with some words in the respondent's native language to facilitate the understanding of questions. This additional vocabulary was acquired prior to commencing the survey.

2.6 Pilot study of retailers' questionnaire

The pilot study of retailers was conducted during February 2017. Two retailers were selected randomly from outside the research sample and their consent was obtained to participate as respondents to highlight the products being sold and their activities in dealing with farmers directly giving advice and support on pesticide selection and use. The structured questionnaire was a shortened version of that for farmers and included 44 questions investigated different aspects to characterise the company and respondent, work experience, pest and disease identification and health and safety awareness and precautions.

2.7 Survey of retailers

Pesticide retailers in the same wilaya as the FA and nFA farms were targeted. Some of the targeted retailers were selected, for their locations, through the agriculture development directorates located in the same wilaya and the rest of them were identified by driving between the commercial areas where they located. The survey was carried out from March to July 2017 and covered 75 retailers located in the same seven governorates (consists of wilayats) as the farmers. Face-to-face interviews were held on the retailer's premises. Each interview lasted between 30 and 60 minutes and was conducted in Arabic and/or English depending on the participant's background. Retailers were questioned on their capability to diagnose the same pests and diseases as the FA and nFA groups. They were also probed on the selection of appropriate pesticides for the same problems and their awareness about the potential adverse impacts of pesticide on the environment and human health (see chapter 6).

2.8 Focus group

Stage four of the data qualitative collection utilized a focus group where FA members were gathered and invited to discuss different issues related to pesticides based on their experiences. The purpose here was to understand their perceptions and attitudes on some issues relating to pesticide application that had not been covered in the farm-based questionnaire.

It was not possible to involve nFA respondents in focus groups since there was no route by which these respondents could be gathered, as there is no association or leadership structure to provide a list of names and contact details. In addition, most nFA respondents were expatriates, working individually in rented or sub-let farms. Respondents of this group were often hesitant to participate in such conversations due to a fear of incurring prosecution especially when some of their labourers might be illegal migrant/immigrant workers. The difficulties in gaining access to some of the nFA farms have been mentioned above. Attempting to have them in a focus group discussion may increase their reluctance to participate and fear of prosecution. Hence, it was deemed inappropriate to gather a group of nFA respondents for discussion.

Thirteen FA farm owners participated in the group discussion. Farmers were selected randomly and they represented the vegetable producers in Oman. The discussion was held at the FA's head office in A'Suwaiq wilaya at Al Batinah north on 15 February 2017. The farmers were allowed to express their perceptions and experience on the topics discussed. The discussion was started with an introduction about the topic and the main objectives of the study and guaranteed anonymity of the participants to give the farmers more confidence to express their opinions. Six open-ended questions were posed (Appendix 3.6) with the discussion conducted in Arabic. The total time allowed for discussion was 90 minutes. The questions were designed to understand the farmers' attitudes in terms of pesticide application and especially their approach to dealing with pesticide resistance. There was no limited time given to each question or to any farmer and all the farmers were free to talk about their experience as required. The discussion was managed not just by asking questions but also by discussing farmer's queries as they arose. This encouraged farmers to explain their perceptions of pesticide use in more detail.

2.9 Statistical analysis

Mean ranks for non-parametric data from the survey questionnaires, including Likert scale questions, were compared using either the Mann-Whitney U-test (for two groups) or Kruskal-Wallis analysis (for more than two groups) (Lyman Ott, 1993).The data were analysed using statistics calculator (https://www.socscistatistics.com). Within Kruskal-Wallis analyses, where significant differences in mean rank were indicated ($P \leq 0.05$), individual mean ranks were separated by using the z-value for significance threshold (Gwet, 2011) implemented within Microsoft Excel. In all analyses, the 5% probability value ($P=0.05$) was taken to indicate significance in differences between rank averages or a significant correlation between variables.

Chapter 3. Factors affecting farmers' ability to identify major pests and diseases of some vegetable crops.

3.1 Summary

This study investigates the ability of vegetable growers in Oman to diagnose the most common vegetable crops pests and diseases and the factors that affect the farmer's diagnostic ability. The study was conducted by surveying one hundred and sixty vegetable growers in seven regions located in the northern part of the Sultanate of Oman. In general, the 40 respondents who were members of the Omani Farmers' Association (FA) revealed better identification skills than the 120 who were not – designated as a non-Farmers' Association (nFA) group in the survey. There were distinctive effects of status, experience, education level and training on a respondent's ability to diagnose the crop problems. There was a significant difference between FA and nFA respondents within the same Wilaya (area) and between FA and nFA respondents in Al Batinah regions but not between Al Batinah and other regions perhaps due to knowledge diffusion amongst groups in the same area. The study recommended the need to improve farmers' awareness, knowledge and skills in diagnosing the economically important pests and diseases attacking their crops. These problems could be tackled through designing applied and effective crop protection training programmes including pest and disease diagnosis. Training would not only improve the technical capabilities of governmental extension services, but also the pesticide retailers who play an important role in helping farmers deal with crop protection issues.

Key words: Farmers' Association; Diagnosis of pests and diseases; Training of farmers

3.2 Introduction

Agriculture in Oman was improved in the last four decades supported by subsidies provided by the government to sustain livelihoods of the local farmers in their rural areas and improve crop production. In the past, farmers were concentrated in supplying the local market but in the last two decades farmers shifted towards global food supply and now sell their products in international markets. This new situation imposes some new production strategies so that farmers can fulfil exportation quality demands including those of pesticide residues. Vegetables are the main crops that attained the attention of this shift towards exporting produce. Vegetable production occupies 19% of the total cultivated area in Oman. The area of vegetables increased from 21840 to 22260 ha between 2015 and 2017 with an increase in production from 770 tons to about 815 tons in the same period (MAFWR, 2017). The top ten vegetables in terms of tons produced, included tomato, pepper, eggplant and melon. Tomatoes ranked at the top of the vegetable crops and constituted 11% of the total area under vegetable cultivation and 24% of the total vegetable production (MAF, 2017). However, vegetable production in Oman, as in other parts of the world, encounters many challenges and constraints such as pests and diseases, salinity, marketing, labour and insufficient irrigation water. Pests and diseases are the most critical, substantial and extreme challenge to growers in Oman due to favourable climatic conditions throughout the year (Al-Sadi et al., 2011, Al Adawi et al., 2013, Al-Mawaali et al., 2013, Al-Sadi et al., 2014 and Al-Jaradi et al., 2018). Temperature remains very favourable for pest and disease establishment and proliferation especially in winter when it varies between 15 and 30°C. In summer, temperature exceeds 40 °C and dusty winds make the crop microenvironment more favourable for certain types of sucking insects such as mites, aphids, thrips and others (Shabani et al., 2018).

3.2.1 In-farm situation

Vegetable farms based on management practices, can be categorised into three types: farms managed by owners, farms managed by tenants and farms sub-let to others by tenants. However, it is also useful to divide the farms into two groups based on membership of the Farmers' Association. In this study, members of the Farmers' Association (FA) are distinguished from those who are not, designated in this thesis as a non-Farmers' Association group (nFA). In the farms managed by owners, the owner takes decision in crop protection practices but in other farms, the tenant or foreman takes the responsibility. In both cases, pesticide retailers play a major role in crop protection support and so, are included in this research.

3.2.2 Diagnosis of pests and diseases

Pest and disease diagnosis can be expressed as a first step or process by which the crop problem can be managed or tackled. It has been shown that pests and diseases pose a major threat to crop production worldwide (Oerke and Dehne, 2004, Ruttan, 2005 and Oerke, 2006). In some areas of the world such as tropical countries, high temperature and humidity leads to rapid multiplication of pests and diseases (Abhilash and Singh, 2009). The first and important part of an efficient crop protection programme is the correct diagnosis of the pests and diseases attacking the crops. However, the farming and farmers' situations differ from one country to another and are influenced by many factors such as education, age, gender, experience, training, location, knowledge diffusion and farmer-to-farmer interactions (Wang et al., 2017 and Akter et al., 2018). In some areas of the world like Papua New Guinea, although sweet potato growers were able to identify crop problems and there is strong evidence that pests and diseases still have a large impact on production, but still current management efforts are inadequate (Gurr et al., 2016). In Tanzania however, the situation is different. According to Adam et al., (2015), sweet potato growers could identify diseased plants but they could not distinguish different types of diseases. Out of 194 vegetable growers being interviewed from seven different regions in Cameroon, only 18% of respondents were able to identify vegetable pests (Abang et al., 2014). In some agricultural areas, farmers may be better able to identify different pest and diseases. In Ethiopia, though farmers might not clearly understand the real causal agents of crop diseases, yet they are aware of the damage caused to crops by diseases such as the cereal rusts, smuts, powdery mildews, and bulb/root rots (Kiros-Meles and Abang, 2008). Better findings were obtained in a study conducted in three countries in south Asia including Laos, Cambodia and Vietnam (Schreinemachers et al., 2017). The results showed that 74% of the respondents were able to identify moths and caterpillars, damaging their crops. On the other hand, they were much better in identifying harmful arthropods (69%) than identifying beneficial arthropods (23%). These findings indicate that diagnostic skills differ from one country to another, but it is clear that their inability to identify the problems may partly explain the global scale of losses due to pests and diseases. Overall, it has been estimated that

> "An average of 35% of potential crop yield is lost to pre-harvest pests worldwide. Waste losses along the rest of the food chain - transport, pre-processing, storage, processing, packaging, marketing and plate waste - account for another 35%." (IWMI, 2007).

3.2.3 Factors affecting pest and disease diagnosis

There are many factors affecting a small-scale farmer's ability to identify major pest and diseases attacking their crops. Some of these factors may be a lack of education, experience and training. For many small-scale farmers, knowledge diffusion has an important effect since farmers share information regardless of its correctness. In some parts of the world, other parties such as pesticide retailers also play a major role in supporting farmers in the identification process especially in the absence of government officials or non-governmental extension services. The situation for small-scale growers is similar even in developed countries like the USA. Grasswitz (2019) reported that the effectiveness of pest problem scouting by farmers may be limited because of their limited pest recognition skills.

3.2.3.1 Education

Growers in rural areas of developing countries often lack much education. This may affect their ability to diagnose pest problems attacking their crop frequently unless there is governmental or non-governmental support to farmers. In a survey addressed of 150 market gardening producers of vegetables in the littoral area of Togo, 36% had above primary education level and only 6% were illiterate (Adjrah et al., 2013). In Pakistan, 318 cotton growers were interviewed to identify constraints in the adoption of Integrated Pest Management (IPM) and to analyse implications for the adoption of alternative crop protection strategies at the farmers' level. The authors found that about 6% of the respondents had obtained graduate degrees whereas 26.4% of them had never been in the school and could not read or write (Khan and Damalas, 2015). According to Rijal et al. (2018), out of 180 vegetable growers who participated in a survey on pesticide safety and pest management practices in Nepal, more than 40% had a secondary level education (10th grade) followed by literate (27%), illiterate (22%), higher secondary (12th grade – 7%) and university graduates (3%). In Oman, Al Zadjali et al. (2014) reported that a considerable proportion of the respondents (owners and workers) were uneducated (44 or 20.7% of the total) or only had an elementary education level (70, 32.9%). In a study of grain growers in Australia, where the respondent's (growers and agronomist) education level was relatively high, powdery mildew was correctly identified by (79% of growers and stripe rust by 71% of growers. About 50% of growers correctly identified blackleg on canola while 83% of agronomists did so (Wright et al., 2016). This study revealed that there can be a positive correlation between education level of farmers and their ability to identify pests and diseases.

3.2.3.2 Experience

In the countries where the farmer's education level is relatively low, good agricultural practices including correct diagnoses of pests and diseases depends on their experience. In a study conducted in Ethiopia to assess the farmer's knowledge and management of pea weevil, Mendesil et al. (2016) demonstrated that farmers' knowledge of pea weevil was positively and significantly associated with gender, farming experience and membership of co-operatives. However, their farming experience is affected by the sources of basic information that could come from another farmer, retailers or previous knowledge (so called first-hand experience) which the farmers rely upon. In the state of Wyoming, USA, a study was conducted to understand how farmers made decisions about insect pest management. The results showed that farmers were obtaining and exchanging information with their neighbours. Although neighbours were not the only source of information, they were an important variable in guiding a grower's insect pest management strategy (Noy and Jabbour, 2020).

3.2.3.3 Training

For many farmers, some crop problems are not easy to identify and, in such cases, training plays a major role in pest and disease diagnoses. Uneducated or less experienced farmers are unable to identify major pests and diseases attacking their crops not only due to low level of knowledge, but also due to limited access to information resources such as books, the internet and others. According to Wright et al. (2016), identification of leaf diseases is the first training required by the growers and agronomists of grains in Australia. They reported that growers and agronomists should have a good knowledge of endemic diseases in their crops. The results of a study conducted in Cameroun to identify and evaluate farmers' local knowledge and perception of vegetable pests and diseases indicated that only 36% were members of a farmers' group or association and had attended a workshop while as few as 13% had participated in training programmes on vegetables (Okolle et al., 2016).

This study aims to evaluate the ability of the farmers to diagnose the common, economically important pests and diseases of some vegetable crops in Oman. The findings would help to answer the main research question if farmers can identify the common pests and diseases attacking vegetable crops and what factors may affect their ability. The results are used to test the hypothesis that "FA members identify pests and diseases more accurately than non-FA members".

3.3 Materials and Methods

3.3.1 Introduction

This section describes the methodology designed and used to address the research questions (see Chapter 1, section 4, and Chapter 2). It includes both qualitative and quantitative data collection methods using the questionnaires, which were executed by face-to-face interviews. In Oman, where the postal service is not commonly used by the farming community and internet access is limited, the only way to approach respondents is to visit them in person and gather the required information through a face-to-face session. According to Bulmer (2004), the questionnaire is a research method used to acquire information on participant social characteristics, present and past behaviour, standards of behaviour or attitudes and their beliefs and reasons for action with respect to the topic under investigation. The face-to-face survey is a personal interview approach that probes the answers from the respondents and can give the participants the chance to explain their answers in detail, so that researchers can understand and collect the needed feedback easily and directly (Galletta, 2013 and Hesse-Biber, 2016). Although the questionnaire is a widely used and common method for researchers to collect information from respondents in different fields, considerable thought needs to be given to the structuring of the questionnaire itself.

Based on these principles, the most important point when developing questions for this research was to find a structured way to collect the information required from the respondents and avoid leading the respondents to the answers that were anticipated or perhaps even required. It was also important to avoid questions that would have allowed the respondents to give answers that reflected their own biases. The types of questions, of course, varied according to the type of information required. In the current survey 64 questions were included in the farm-based questionnaire and ethical clearance was obtained from the University of Reading to administer it (Appendix 2).

Prior to the interview, all respondents were informed orally and in writing that their participation in the survey would be kept anonymous. The participants and respondents were also informed through a well-constructed document (Appendix 1) about the identity and background of the researcher and the purpose of interview.

The contact details of researchers and supervisors were also provided in the same document to facilitate the participants and respondents in any future correspondence or if the respondent decided to withdraw from the survey at some time in the future.

The overall survey cohort consisted of two separate groups of participants: those from farms affiliated to the Farmers' Association (FA) and those from farms not affiliated to the Association (nFA) Prior to the deployment of the FA and nFA participant questionnaire, a pilot study was conducted to test the robustness of the questions.

3.3.2 Pilot study of farmers' questionnaire

Prior to the commencement of large-scale surveys, pilot studies are commonly used to test the questionnaire - frequently improving the likelihood of success of the main questionnaire (Mendesil et al., 2016). Pilot studies aim to examine both, the structure of the questions and reflections from the respondents before designing or structuring the last suitable draft of the research questionnaire. Researchers are able to identify deficiencies and problems or limitations in the questionnaire and change or ameliorate them before commencing the main survey. Pilot studies help to examine the main questionnaire to ensure the applicability of the questions to the requirements of the main objectives of the research. Thus, a pilot study is a preliminary stage used to test the methodology of the intended research project, hopefully leading to the success of the large-scale questionnaire (Leon et al., 2011).

The pilot study was conducted in March 2015 in Samail Wilayat located in the interior region of the country. Three farms were selected outside the intended research area. Selection was based on the crops grown since the study focused on vegetable growers. As an outcome of the pilot study, many questions were modified. Most of the questions were revised, restructured and rearranged. The space allowed for answers was also increased to make it easier for the interviewer to record detailed responses.

The first draft of the questionnaire contained seven sections:

- Demographics
- About the respondent
- Diagnosis and pesticide selection
- Appropriateness of pesticide application
- Safe use of pesticides
- Pesticide legislation
- Retailer's response

After the pilot study, the questionnaire consisted of eight sections (Appendix 2):

- General information
- About the respondent
- About the farm
- Pest and disease diagnosis
- Pesticide use and application
- Risk, health and safety
- Pesticides in store
- General comments

Questions referring to the name of the owner and interviewee's contact details were omitted in order to give more confidence to the respondents regarding their anonymity/confidentiality. The final draft at the end, included the name of the interviewer, the date of the interview and a unique participant number. Questions about the respondent in terms of his or her status on the farm, responsibility for pest diagnosis and pesticide selection were included to ensure that the researcher was interviewing the most appropriate person who is making decisions about pest and disease diagnoses on the farm.

The pilot study also identified the need to obtain information about the pre-harvest interval and its importance for consumer health and safety. Questions were also added to the questionnaire to investigate the actions taken by farmers when they observe a lack of efficacy of the pesticide they use. Different possible answers may indicate resistance development which should be investigated further in future research.

In the diagnosis section, the respondents were shown photos of different plant problems and asked to identify them in order to check their capability to diagnose the problem before selecting and using pesticides. After the pilot study, the binary answer choice of YES or NO was amended to include a DON'T KNOW option to provide a third choice to cover unsure or doubtful responses.

3.3.3 Survey of FA and non-FA participants

In the final version of the questionnaire deployed for the survey, various types of questions were used including pictorial identification, open-ended questions, demographic questions and Likert scale questions, depending on the data required from the respondents. Images were used in the section dealing with Pest and Disease Diagnosis to check the ability of the respondents to identify different and common vegetable pests and diseases in Oman. Since most of the respondents were likely to be expatriates from south/east Asia, there was a strong possibility that Arabic or English names might have caused additional confusion, so images of the problems were used. Nevertheless, any local or other pest and disease name in their own language or even what to do to control the problem were all accepted as correct information.

Open ended questions were used to collect more detailed information from the respondents based on their knowledge, experience and understanding. Because of the increased complexity of the associated analysis, this type of question was not used frequently in this study. An open-ended question was, however, used in the section on Pesticide Use and Application, to ask the respondent to explain how pesticides were normally applied.

Demographic questions were used in the questionnaire to collect the basic information of the respondents such as age, education level and qualifications. Likert scale questions are easily deployed and are usually reliable for assessing attitudes or performances in different subject areas. This type of question was developed by the social psychologist Rensis Likert in 1932 (Likert, 1932). The method was devised to give five to seven or even more options to the respondent for each question. The answers of Likert type questions vary from strongly positive to strongly negative with a neutral point in the middle. Likert scale questions may reduce the bias in the answers of the respondents who are tempted to give the socially-accepted answers rather than giving a true reflection of knowledge or action. This technique may also allow the researcher to know the variation or complexity of respondent's attitudes, and consequently give better understanding of respondents thinking and feeling. The Likert scale method was used mainly in the Risk, Health and Safety part of the questionnaire where respondents were asked to provide answers using a five-point scale incorporating NEVER, RARELY, SOMETIMES, USUALLY, and ALWAYS.

Qualitative data collection consisted of four stages:

Stage one targeted respondents from farms aligned with the Farmers' Association (FA). In stage two, respondents from farms not aligned with the Association (nFA) were targeted. In both stages, qualitative data on pest and disease diagnosis, pesticide selection, pesticide application and the potential adverse effects of pesticides were collected and investigated through a series of face-to-face interviews conducted on the farm. The FA farms were selected from the list of FA members provided by the FA chairman of farmers' association for FA group and for the nFA group, the Agriculture Development Directorate located in each wilaya provided information allowing selection of farmers based on the crops they grew. Some nFA farmers were also selected by walking around vegetable farms in the same area and asking the owner, foreman or tenant if he or she was interested to participate in the study.

In stage three, pesticide retailers in the same wilaya as the FA and nFA farms were targeted. Retailers were also questioned on their capability to diagnose the same pests and diseases as the FA and nFA groups. They were also probed on the selection of appropriate pesticides for the same problems and their awareness about the potential adverse impacts of pesticide on the environment and human health.

Stage four utilized a focus group where FA members were gathered and invited to discuss different issues related to pesticides based on their experiences. The purpose here was to understand their perception and attitude on some pesticide application areas that had not been covered in the questionnaire. It was not possible to involve non-FA respondents in focus groups since there was no route by which these respondents could be gathered, as there is no association or leadership structure to provide a list of names and contact details. In addition, most of nFA respondents were expatriates, working individually in rented or sub-rented farms. Respondents of this group were hesitant to participate in such conversations due to a fear of penalization especially when some of their labourers might be illegal migrant/immigrant workers. Every effort was made to address these concerns by making it clear that this was a student project both informally by wearing appropriate clothing, use of a privately-owned vehicle and formally, by a written guarantee of complete anonymity. As already noted, respondents' names were not recorded.

3.3.4 Survey of Farmers' Association members

The survey was carried out from April to May 2015 on vegetable farms in the Al Batinah south and north coastal areas of northern Oman (Figure 3.1). Each farm was visited in person by the interviewer, for a period between half to one hour, depending on the farmer's knowledge and experience. The interviews were conducted in Arabic since all the FA members were Omani nationals with Arabic as their native language. In addition to completing the questionnaire, farmers were asked to show pesticides stored on the farm in order to investigate the type of pesticides they are using and to distinguish between proprietary and so called "me-too" products (see Al Zadjali, 2014).

3.3.5 Survey of non-Farmers' Association (nFA)

One hundred and twenty respondents were interviewed in the period from November 2015 to February 2016. The interviews were conducted during the growing season of most of the vegetables (September to March each year). The same questionnaire as used for the FA respondents' survey was used for nFA respondents. Because of the ethnic diversity of the respondents, the languages used included Arabic and English with some words used from the country of origin of the respondents to facilitate the understanding of questions. This additional vocabulary was acquired prior to commencing the survey.

The survey covered the seven major vegetable production governorates in Oman (Figure 3.1) and included Al Batinah north and south, Ash Sharqiyah north and south, Ad Dakhliyah, Adh Dhahirah and Al Buraimi. The interviews were held face-to-face and the time for each interview varied from half an hour to an hour depending on the knowledge and experience of the respondents.

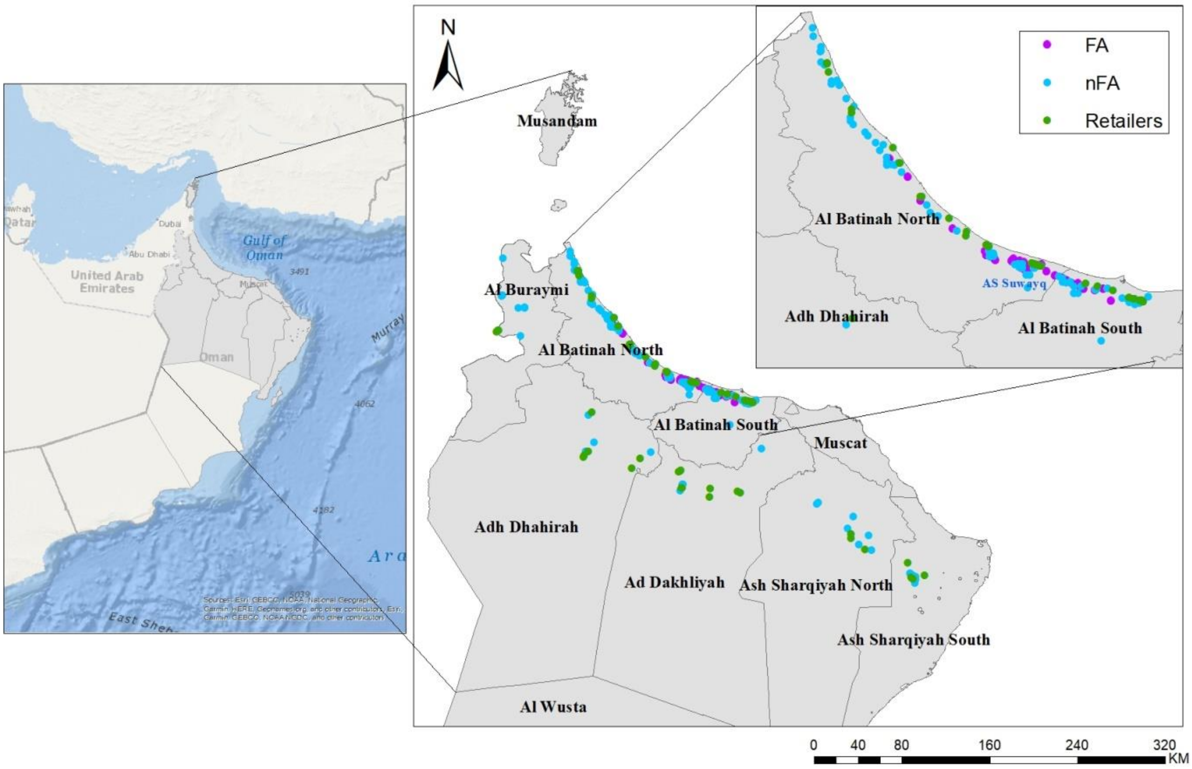

Figure 3.1 Map of the Sultanate of Oman showing locations of the FA, nFA and retailers' respondents who anonymously agreed to participate in the research work. The surveys include 40 FA, 120 nFA and 75 retailers scattered all over the vegetable production areas in the country (The researcher, 2021).

3.3.6 Statistical analysis

Mean ranks for non-parametric data from the survey questionnaires, including Likert scale questions, were compared using either the Mann-Whitney U-test (for two groups) or Kruskal-Wallis analysis (for more than two groups) (Lyman Ott, 1993).The data were analysed using statistics calculator (https://www.socscistatistics.com). Within Kruskal-Wallis analysis, where significant differences in mean rank were indicated ($P<0.05$), individual mean ranks were separated by using the z-value for significance threshold (Gwet, 2011) implemented within Microsoft Excel. In all analyses, the (5%) probability value ($P=0.05$) was taken to indicate significance in differences between rank averages or a significant correlation between variables (Pearson and Spearman’s rank correlation).

3.4 Results

3.4.1 Status of respondents

The owner group serving as respondents represented a higher proportion of FA farms (40%) than nFA farms (5%). Among nFA respondents, tenants and foremen were the main respondents (85%). Ten workers were recorded as respondents within nFA farms but there were no workers classified as respondents in FA farms (Figure 3.2). Amongst FA and nFA, tenants represented the highest proportion of respondents (45%).

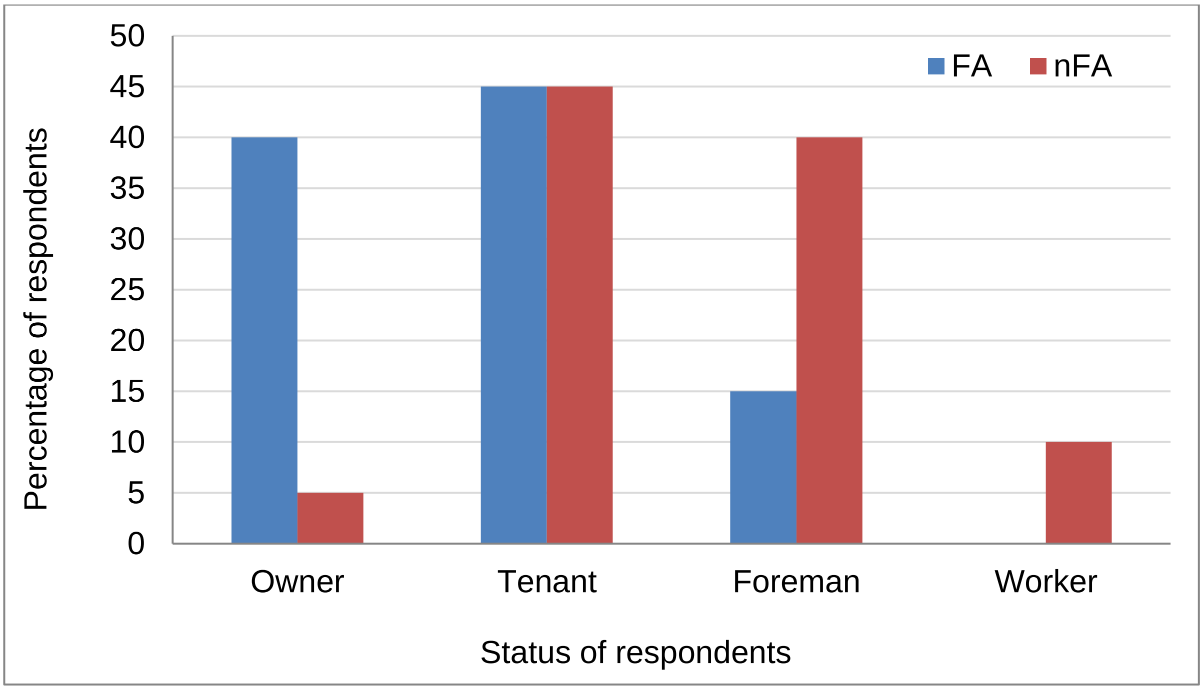

Figure 3.2 Status of FA (n=40) and nFA (n=120) respondents. Tenants constituted the highest percentage (45%) for both groups.

3.4.2 Responsibility for diagnosing crop protection problems

Amongst FA respondents, owners constituted 40% of the respondents that took responsibility for diagnosing pests and diseases. Tenants represented 30% of FA respondents responsible for diagnosing crop problems while foremen became in the third category with (12.5%) (Table 3.1). Within nFA respondents, foremen were most commonly responsible for diagnosing crop problems with around 36% followed by Tenants (29%) then owners (27.5%). In only one FA farm and one nFA farm were other farmers involved in diagnosis (Table 3.1).

Table 3.1 Status of FA and nFA respondents who were responsible for pest and disease diagnosis.

	FA		nFA	
	N	%	N	%
Owner	16	40	33	27.5
Pesticide seller	3	7.5	4	3.33
FA	1	2.5	2	1.67
Tenant	12	30	35	29.2
Foreman	5	12.5	43	35.8
Tenant and Seller	2	5	2	1.67
Another Farmer	1	2.5	1	0.83
Total (n):	40		120	

3.4.3. Respondents' age

The majority of FA respondents (82.5%) were in the age range of 20 – 50 years (Figure 3.3). Around 72% of the nFA respondents were in the age range of 20 – 50 years showing a higher proportion above 50 years old in comparison to FA respondents. Nonetheless, the mean ages of FA (40.6) and nFA (41.2) respondents were almost the same (Figure 3.3, P= 0.747, Appendix 3).

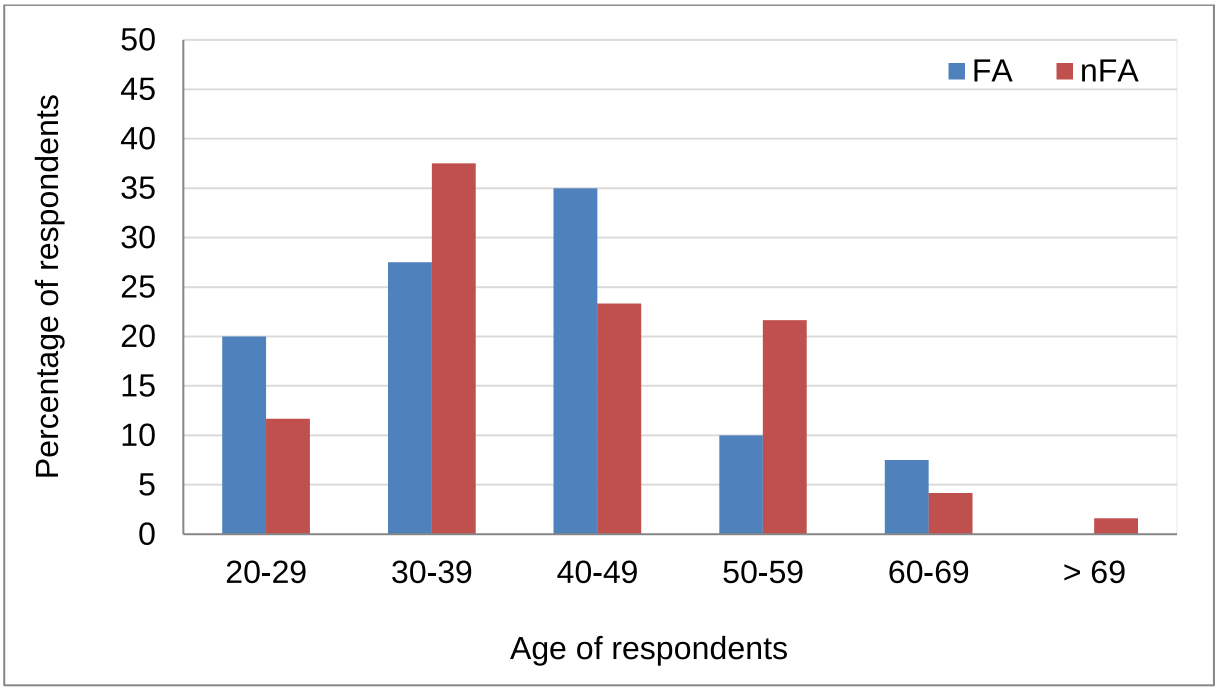

Figure 3.3 Age frequency in percentage of FA (n=40) and nFA (n=120) respondents.

3.4.4 Respondents' ethnicity

In FA respondents, Omanis comprised 90% of the total number (40) followed by Bangladeshis (7.5%) and one Egyptian. Unlike FA, the majority of nFA respondents were Bangladeshis (62.5%) followed by Omanis (21.7%), Pakistani (7.5%), Indians (4.17%), Egyptians (3.33%) and one Afghan. In general, Bangladeshis represented most of the expatriates working in the farms under investigation (Table 3.2).

Table 3.2 Nationalities of respondents among FA and nFA farmers

	FA		nFA	
Nationality	N	%	N	%
Omani	36	90	26	21.7
Bangladeshi	3	7.5	75	62.5
Egyptian	1	2.5	4	3.33
Afghan	0	0	1	0.83
Pakistani	0	0	9	7.5
Indian	0	0	5	4.17
Total (n)	40		120	

3.4.5 Respondents' education level

Most of the FA members were educated. The data showed that about 83% of FA respondents had grade 7 and above education level and only two respondents were illiterate (uneducated), however, 10 respondents (25%) possessed a higher education level (Diploma and above). A significant proportion of nFA respondents (23) were uneducated or had very low education level (48%). Only 10% of the nFA respondents possessed higher education level (Figure 3.4, P=0.002, Appendix 4).

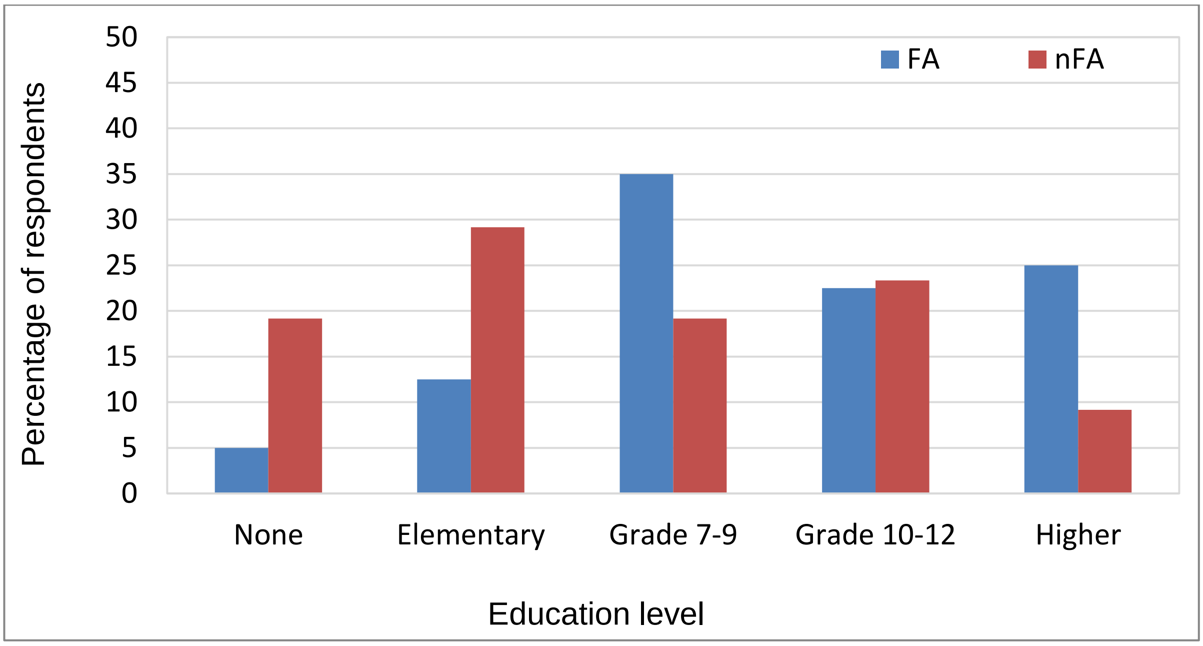

Figure 3.4 Education levels of FA (n=40) and nFA (n=120) respondents.

3.4.6 Experience of agriculture and pesticide use

Although 65% of FA respondents possessed an agriculture experience of 15 years and above in comparison to 59% of nFA (Figure 3.5), still nFA respondents on average had 17 years of experience level compared to the FA respondents (16 years), a negligible and non-significant difference (P= 0.614, Appendix 3).

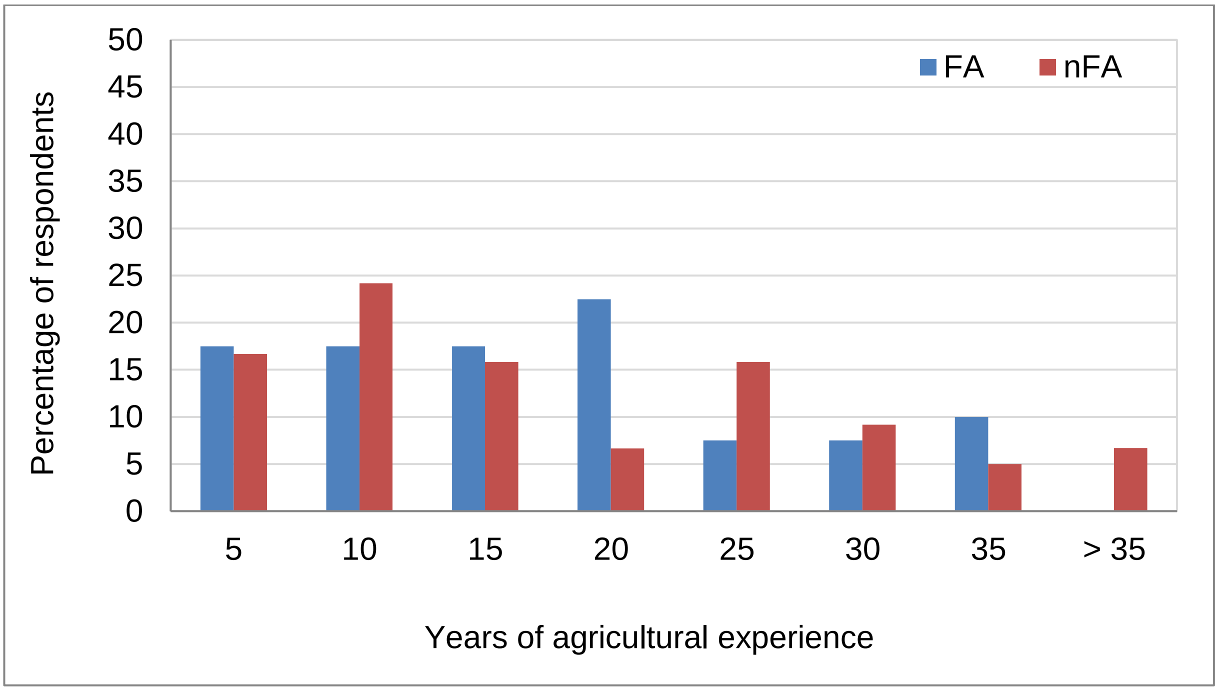

Figure 3.5 Years of agricultural experience of FA (n=40) and nFA (n=120) respondents.

Around 40% of the FA respondents showed five to ten years of pesticide experience in comparison to 58% of nFA respondents. Most of FA respondents (60%) had 15 or more years of pesticide experience while around 42% of nFA respondents showed the same years of experience (Figure 3.6).

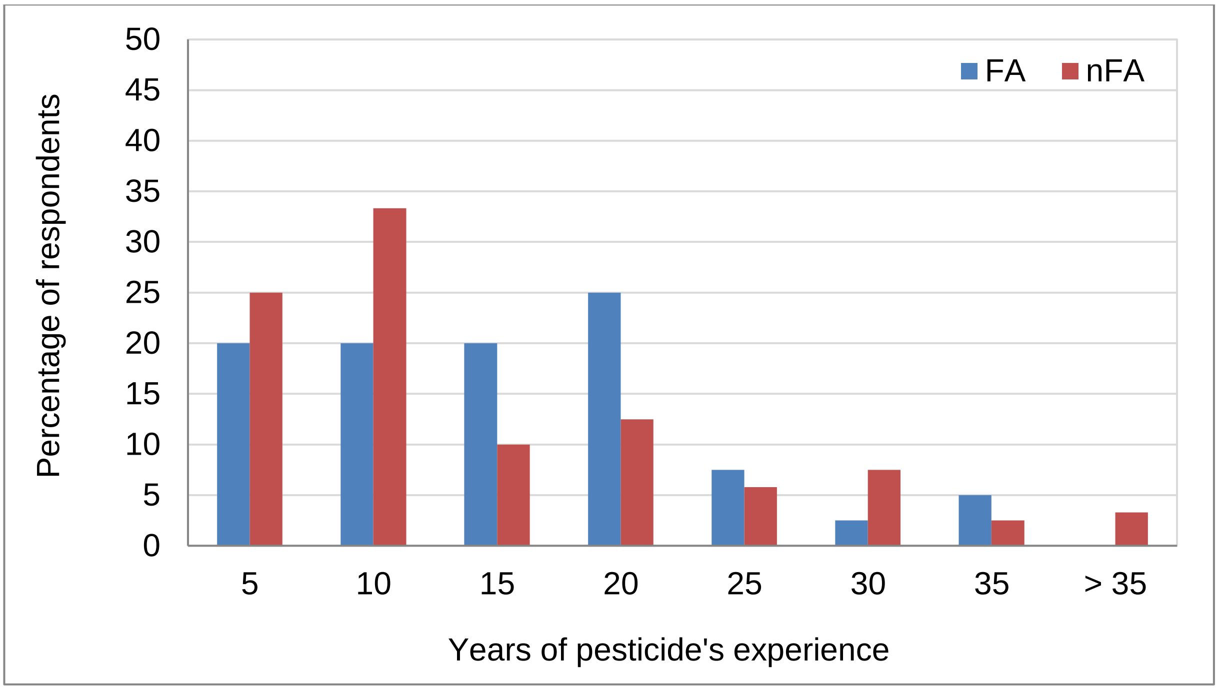

Figure 3.6 Pesticide experience (years) for FA (n=40) and nFA (n=120) respondents.

3.4.7 Training in pest and disease diagnosis

The number of farmers obtaining trainings in both FA and nFA groups was very low (Table 3.3). There were only 5 respondents (12.5%) who had obtained training from FA group. Four of them acquired the training on “safe use of pesticides” and one respondent had attended a course on “good agriculture practices”. Out of 120 respondents, only three from the nFA group (2.5%) had participated in training programmes. One was on “farming” and two respondents had attended a “safe use of pesticides” training programme.

Table 3.3 The number, percentage and type of training programmes in which FA and nFA respondents had participated over the previous ten years.

FA			nFA		
N (out of 40)	%	Type of training	N (out of 120)	%	Type of training
4	12.5	Safe use of pesticides	1	2.5	Farming
1		Good agriculture practice	2		Safe use of pesticides

3.4.8 Respondents' locations

The geographical distribution included in the survey for both FA and nFA farms are shown in (Table 3.4). The survey covered 40 farms of FA and 120 farms from nFA groups. All FA farmers included in the field survey were in Al Batinah south and north governates (Table 3.4). Note that the survey was carried out before 21 December 2016 when the name and scope of the association was enlarged to include all farmers from different governates in one association. Eighty-seven (72.5%) out of nFA farmers were also from the same governates (Table 3.4) which indicates that the majority of farmers responding to the questionnaire were from Al Batinah south and north governates, where the vegetable production thrives with more intense farming activities. Out of nine Wilayats from Al Batinah governates, A'Suwaiq constituted the highest number of farms for both FA (25) and nFA (23), and constituted 30% of the total number of farms included in the surveys (160 farms, Table 3.4). This reflects the intensity of vegetable farming activities and importance of this Wilayat amongst others as a major production governates of vegetables in Oman.

Table 3.4 Geographical distribution of the farms included in the FA and nFA surveys.

Wilayat	Governorate	FA	nFA	Total
A'Suwaiq	Al Batinah north	25	23	48
Al Musanah	Al Batinah south	8	11	19
Sohar	Al Batinah north	2	15	17
Barka	Al Batinah south	2	14	16
Shinas	Al Batinah north	0	14	14
Mhadah	Al Buraimi	0	8	8
Al Kamel	A'Sharqya south	0	8	8
Saham	Al Batinah north	1	4	5
Liwa	Al Batinah north	0	4	4
Al Khaborah	Al Batinah north	1	2	3
Ibri	Adh Dhahirah	0	3	3
Bahla	Ad Dakhliyah	0	3	3
Bidiyah	Ash Sharqiyah north	0	3	3
Ibra	Ash Sharqiyah north	0	2	2
Al Qabil	Ash Sharqiyah north	0	2	2
Dank	Adh Dhahirah	0	1	1
Yanqil	Adh Dhahirah	0	1	1
Al Buremi	Al Buraimi	0	1	1
Nakhal	Al Batinah south	1	0	1
Izki	Ad Dakhliyah	0	1	1
Total		40	120	160

3.4.9 Farm sizes

The farm sizes varied between 5 and 55 ha for FA and nFA farms. However, most of respondents' farm sizes were varied between (1 and 9.9) ha. FA respondents' farm sizes varied between (1 and 25) ha and constituted 80% of the total FA farms, whereas 95% of nFA farms were in this range indicating that FA farm sizes were relatively larger than those of nFA farms (Figure 3.7, P=0.012, Appendix 3).

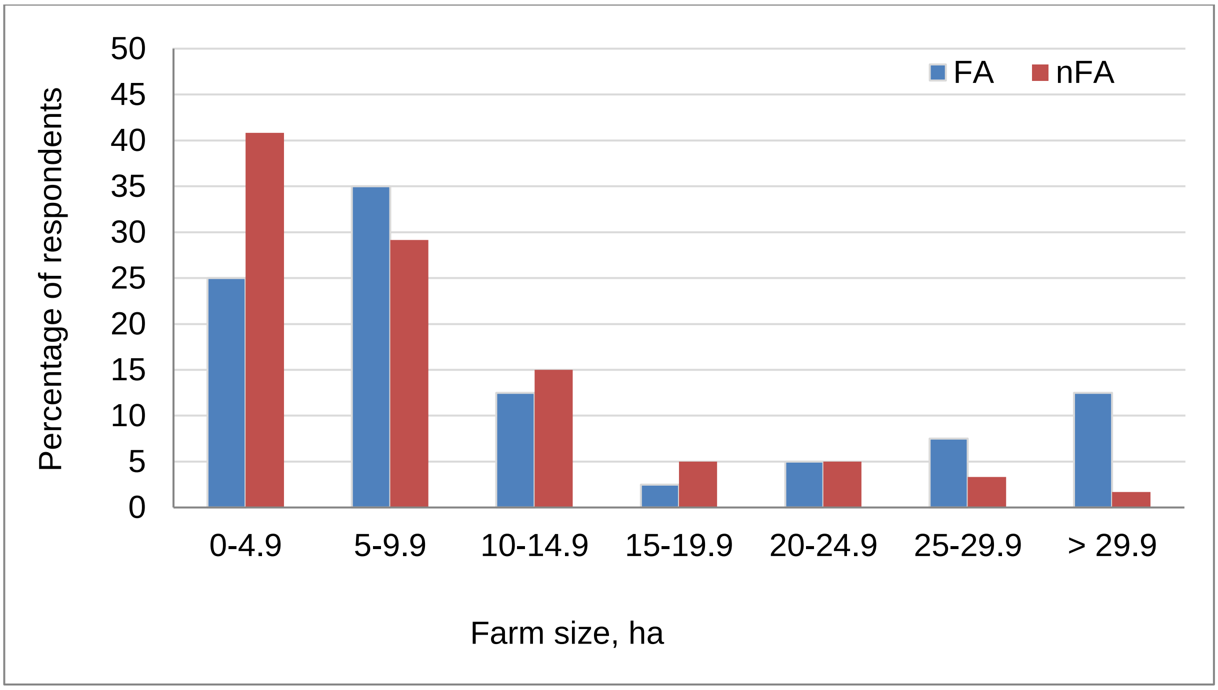

Figure 3.7 Distribution of farm sizes among FA (n=40) and nFA (n=120) respondents.

3.4.10 Sources of advice on diagnosis

Most FA (68%) and nFA (78%) farmers sought advice from the retailers for pest and disease diagnosis (Table 3.5). “Other famers” provided diagnostic advice to about 20% of FA and 6% of nFA farmers. Ministry of Agriculture and Fisheries and Water Resources (MAFWR) provide 15% of the diagnosis information on diagnosis to FA members and 14% to nFA respondents. Only 10% of FA and 3% of nFA respondents reported that they obtained information on diagnosis from FA (Table 3.5). No FA respondents used the internet to find information on diagnosis and only one nFA did so (Table 3.5).

Table 3.5 Main sources of information used to get help on diagnosis of pests and diseases attacking their crops for FA (n=40) and nFA (n=120) respondents. Respondents could indicate more than one source.

Sources of diagnosis advice	FA, %	nFA, %
Retailer	67.5	77.5
Another farmer	20	5.83
MAFWR	15	14.2
FA	10	3.33
MAFWR + retailer	5	1.67
FA + internet	5	0
Retailers + another farmer(s)	5	0
MAFWR + internet	2.5	0
MAFWR + another farmer	2.5	0
Internet	0	0.83
Local/farm practice	0	0

3.4.11 Farmers' Association membership and knowledge diffusion

The majority of FA members had been members for at least five years with 75% joining in 2014 or before. In addition, FA members showed benefits of the participation to the association by sharing the experience and knowledge in pesticide applications through group discussions. According the survey findings, 95% of the FA members were sharing information through group discussions.

3.4.12 Capability of farmers to diagnose different pests and diseases

FA respondents revealed a better ability in pest and disease diagnosis than nFA respondents (Figure 3.8). Most FA and nFA respondents correctly identified spodopteran, whitefly and leaf miner pests. The correct diagnosis of spodopteran, whitefly, and leaf miner pests by FA respondents was 98%, 93% and 85% respectively which was slightly higher than nFA respondents who were able to correctly diagnose (95, 86 and 76%, respectively) ($P < 0.001$, Appendix 5). For the early and late blights and damping off diseases, FA respondents showed high diagnostic ability (>80%) whiles the correct diagnosis of downy mildew, melon decline and aphids was around (50-70%). The lowest level of correct diagnosis represented by FA respondents was for thrips (42%) and powdery mildew (35%). Correct diagnosis of early and late blights, damping off, downy mildew, melon decline, aphids, powdery mildew and thrips within nFA respondents was less than 40%. The lowest ability to diagnose pests and disease for nFA respondents was reported for thrips (12%).

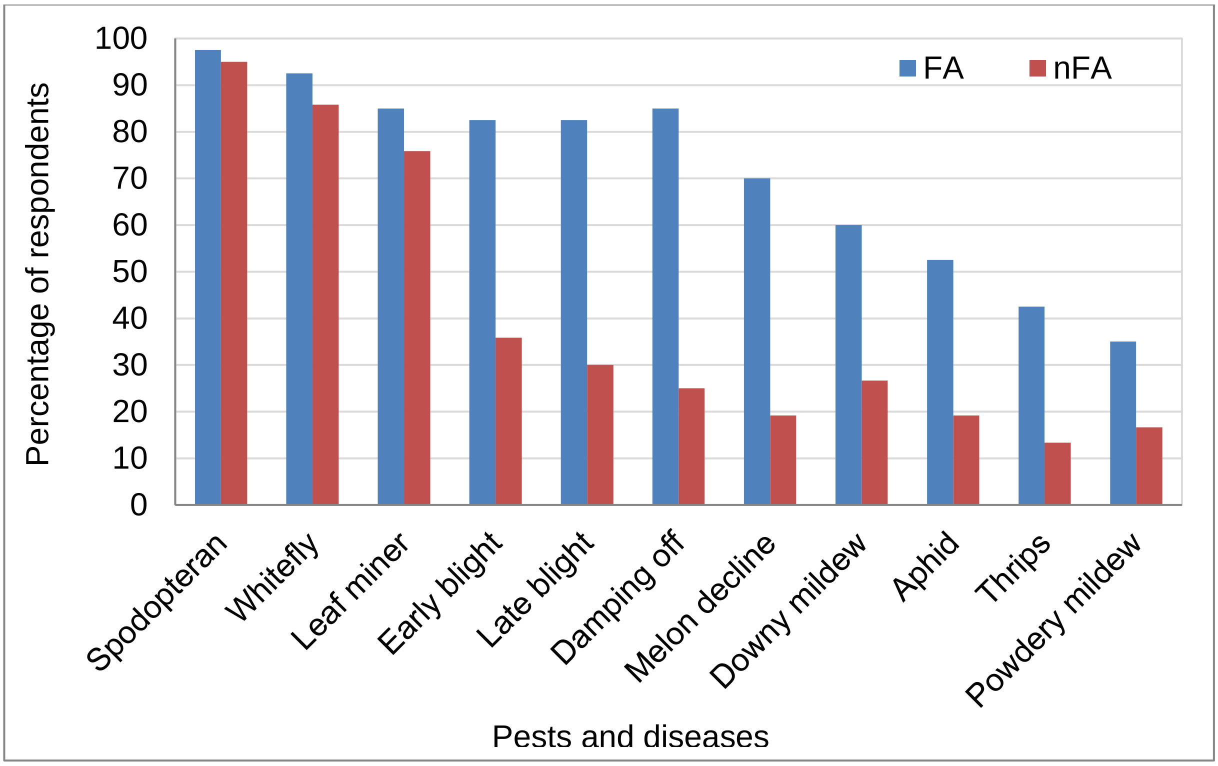

Figure 3.8 Percentage of FA (n=40) and nFA (n=120) respondents who correctly identified eleven pests and diseases of vegetable crops. Statistical analysis is provided in Appendix 5.

Taking in consideration the main crops grown in the respondents' farms, three crops were grown in both FA and nFA respondents' farms including melons, tomato and pepper which were frequently infested by melon decline disease, early blight and thrips respectively. FA respondents showed a significantly higher level of ability to diagnose the major pest and diseases attacking these three crops than nFA. All FA respondents (100%) diagnosed the problem of melon decline correctly, while less than 60% of nFA respondents were able to diagnose the same disease of melons correctly (Figure 3.9). More than 90% of FA respondents diagnosed early blight correctly in comparison to around 50% of nFA respondents. Similarly, in case of thrips identification, FA respondents showed a slightly higher proportion (around 5%) in diagnosing the problem than nFA respondents.

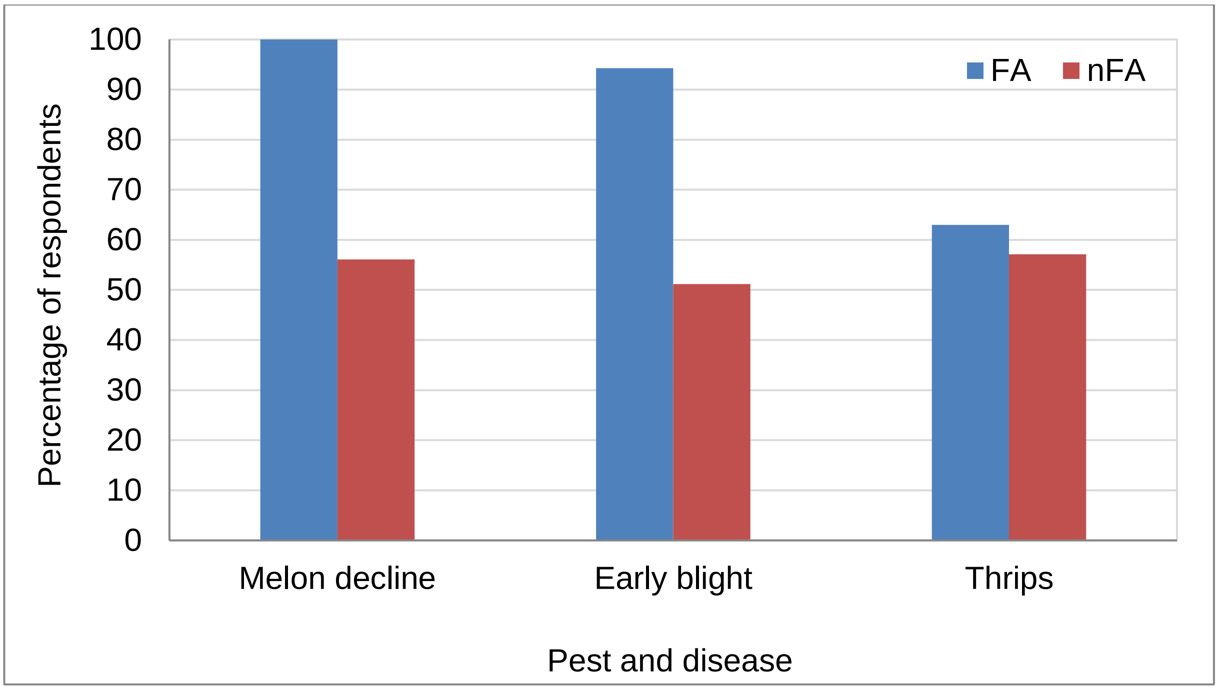

Figure 3.9 Percentage of respondents giving the correct diagnosis among those that were growing Melon (FA, n=27 & nFA, n=41), Tomato (FA, n=34 & nFA, n=84) and Sweet pepper (FA, n=27 & nFA, n=29) for melon decline, early blight and thrips, respectively.

3.4.13 Diagnosis based on status of respondents

Owners revealed higher ability to diagnose pests and diseases for both FA and nFA respondents (Figure 3.10). However, for a given status, FA respondents achieved around 20-35% more correct identifications than the nFA respondents (P< 0.001, Appendix 2.6). Alarmingly, among nFA respondents, foremen, tenants and workers diagnosed less than 40% correctly (Figure 3.10). Pairwise comparisons showed significant differences especially between tenants of both groups (Appendix 6).

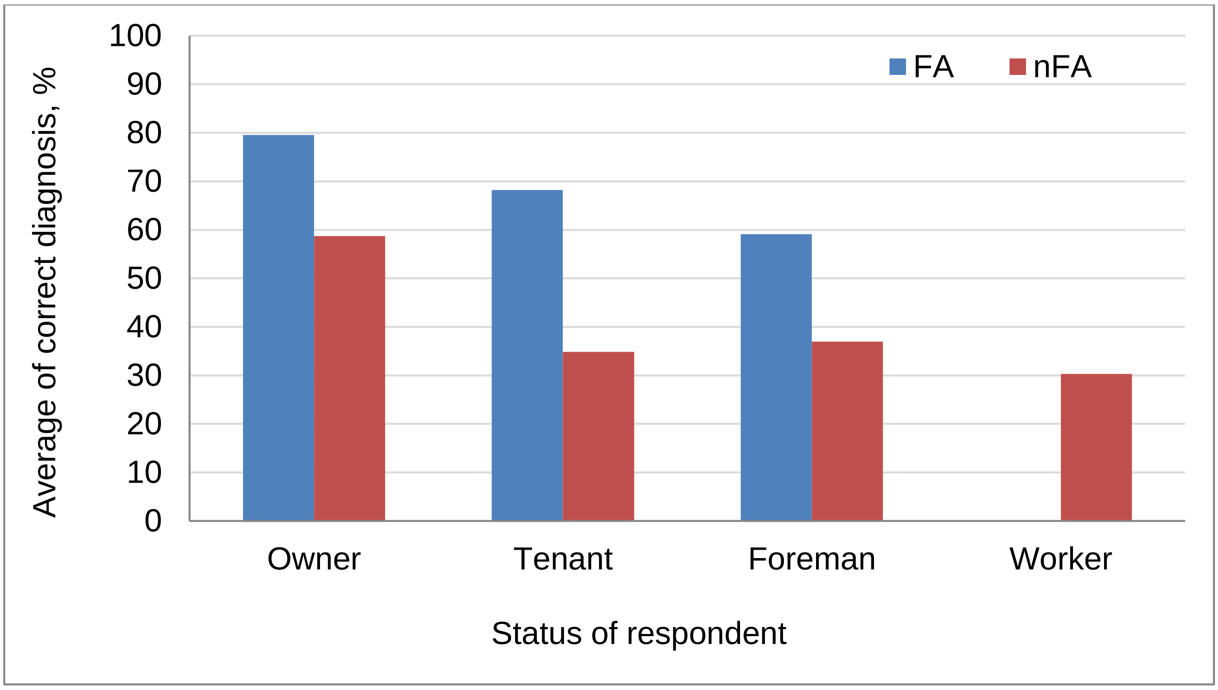

Figure 3.10 Average percentages of correct diagnoses of 11 pests and diseases for FA (n=40) and nFA (n=120) respondents classified by their status. Statistical analysis is provided in Appendix 6.

3.4.14 Effects of respondents' age on diagnostic ability

There was no effect of age in FA respondents' ability to diagnose pests and diseases. The ability to diagnose the problems fluctuated between 65 and 77% over years (20-60) of FA respondents but with no significant trend (Figure 3.11; R^2=0.0001, P>0.05, Appendices 7 (A) and 8). The diagnostic ability of nFA respondents, however, increased from 29 to 58% between the ages of 20 and 60 years then decreased to 18% for an 70 and 80 year-old respondent although the trend with age was also not significant (Figure 3.11; R^2= 0.033, P= 0.474, Appendices 7 (B) and 8). Pairwise comparisons showed that 20-29 and 40-49 year-old FA respondents had significantly better diagnostic abilities than nFA respondents (Figure 3.11; Appendix 6).

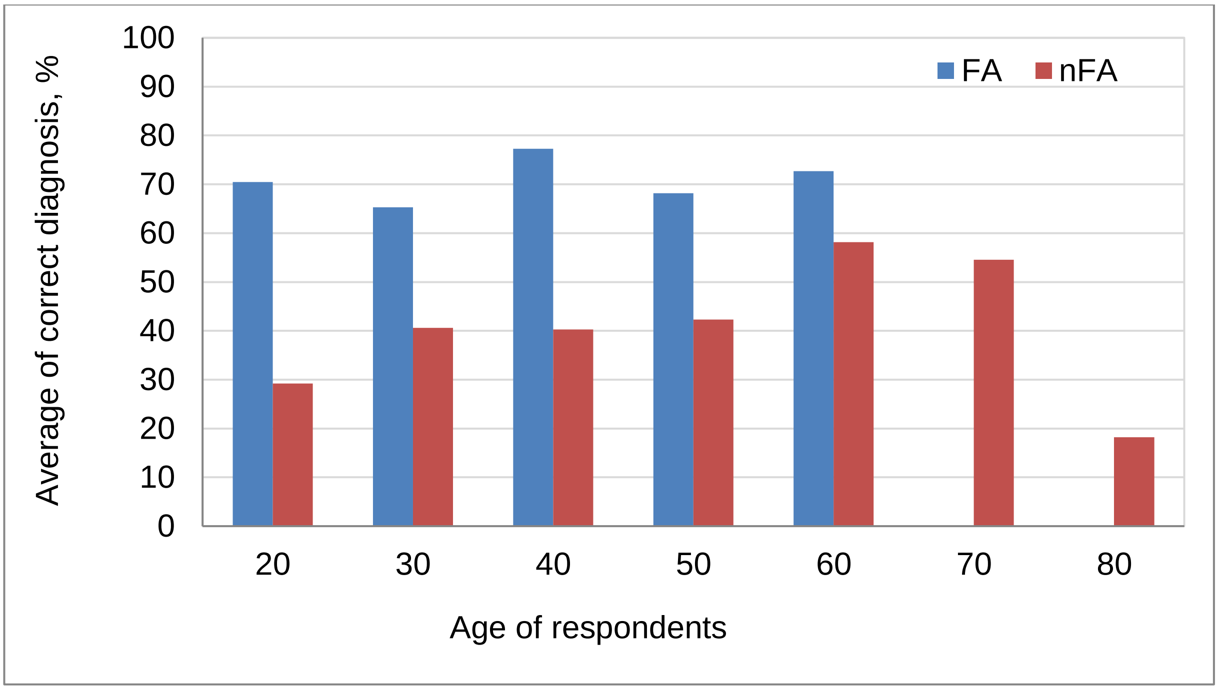

Figure 3.11 Mean percentages of correct pests and diseases diagnosis of FA (n=40) and nFA 9n=120) respondents based on their ages. Statistical analysis is provided in Appendix 6.

3.4.15 Effect of respondents' education levels on their ability to identify pests and diseases.

Overall, diagnostic ability increased with education level for both FA and nFA respondents (Figure 3.12) increasing from 51% to 83% and from 37% to 60% for FA and nFA respondents, respectively as their education progressed from elementary to higher (>grade 9) level, both of these trends being significant (FA: P= 0.011, Appendices 9, A and 10; nFA: P< 0.001, Appendices 9, B and 10). However, there were still significant numbers of well-educated respondents (FA and nFA, but especially nFA), who could not identify the common pests and diseases.

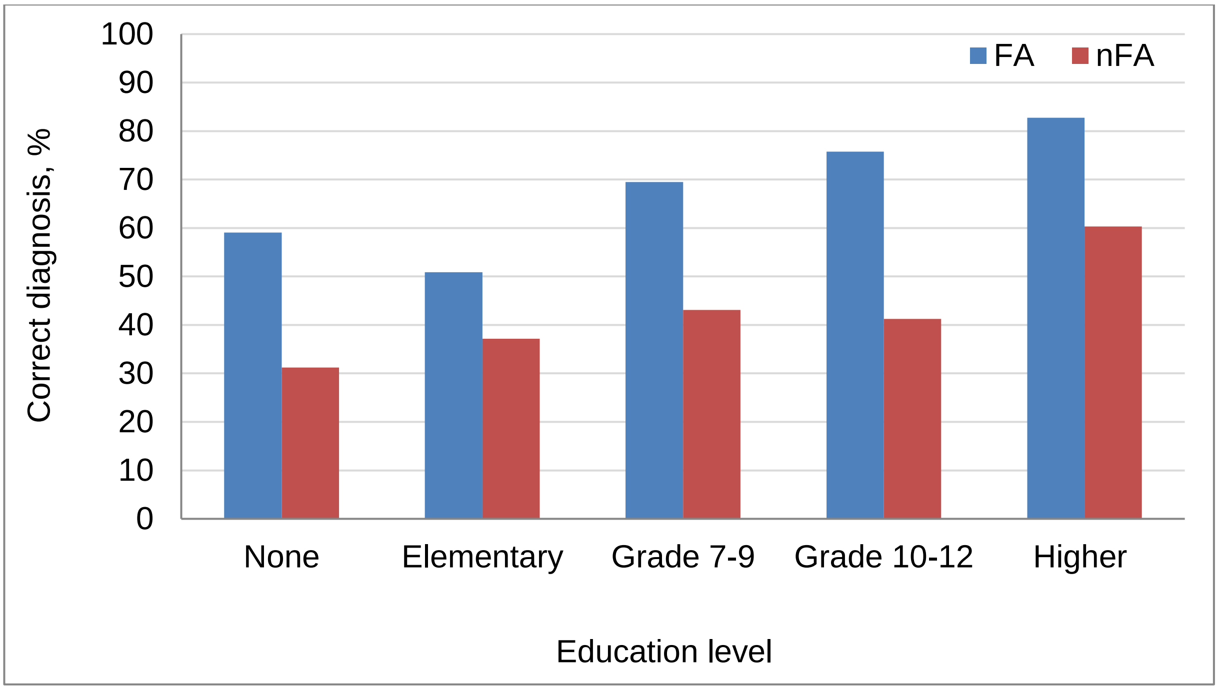

Figure 3.12 Mean percentage of correct identification of pests and diseases of FA (n=40) and nFA (n=120) respondents based on their education level. Statistical analysis is provided in Appendix 6.

3.4.16 Effects of respondents’ agricultural experience on diagnosis

Years of agriculture experience revealed a significant and positive increase in the ability of nFA respondents to diagnose crop problems but not for FA (Figure 3.13; FA: R^2= 0.023, P= 0.352, Appendices 11, A and 12) and (nFA: R^2= 0.113, P< 0.001, Appendices 11, B and 12). As noted previously, However, the percentages of correct diagnoses of the common pests and diseases of FA respondents were higher than those of nFA (Figure 3.13; P< 0.001, Appendix 6). The pairwise comparisons showed the relatively inexperienced (<20 years) nFA respondents performed particularly poorly (Figure 3.13, Appendix 6).

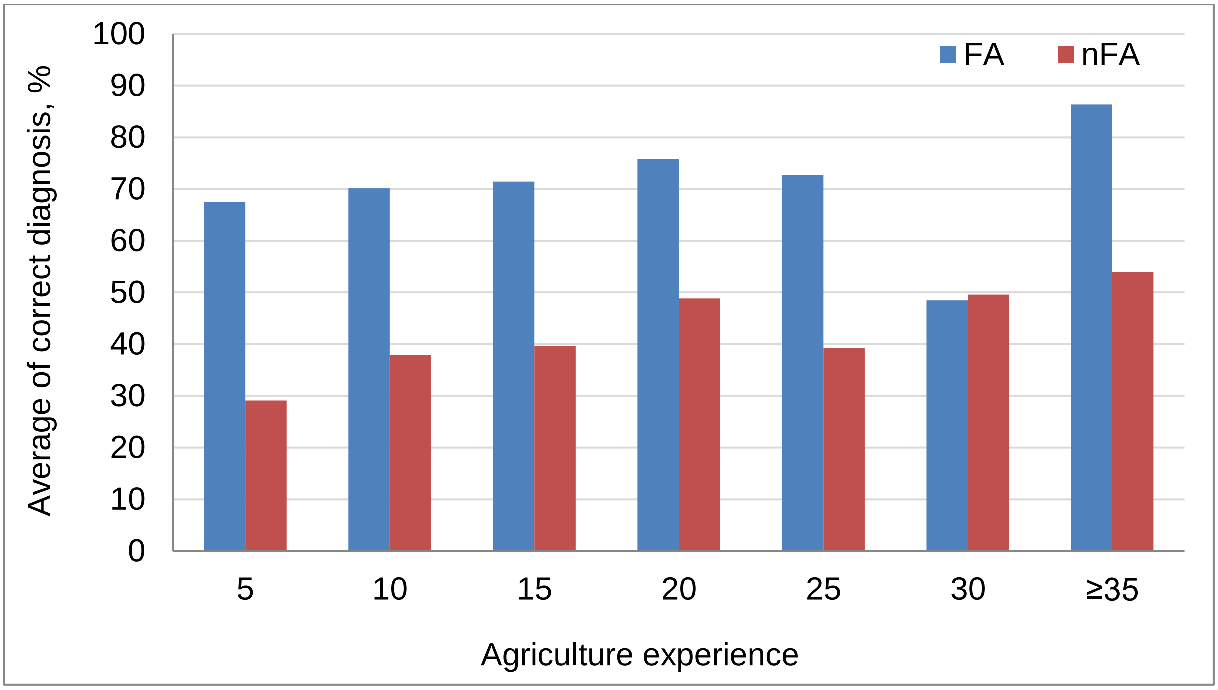

Figure 3.13 Mean percentage of correct identification of pests and diseases of FA (n=40) and nFA (n=120) respondents based on their years of experience. Statistical analysis is provided in Appendix 6.

3.4.17 Effects of respondents' training on diagnosis

It was observed during the survey that only a very small number of respondents had acquired training related to crop protection. Only five respondents from the FA group and three from the nFA had participated in any training programmes related to crop protection. The remaining 152 respondents had never attended any training. Results from training should therefore be treated with caution, but there was no evidence of an effect of training on the ability of FA respondents to identify the crop protection problems but there was on nFA respondents (Figure 3.14). Despite the small numbers, there is an encouraging apparent trend that the trained FA and nFA respondents performed similarly well achieving an average of just under 7/10 correct diagnoses (Figure 3.14, Appendix 6).

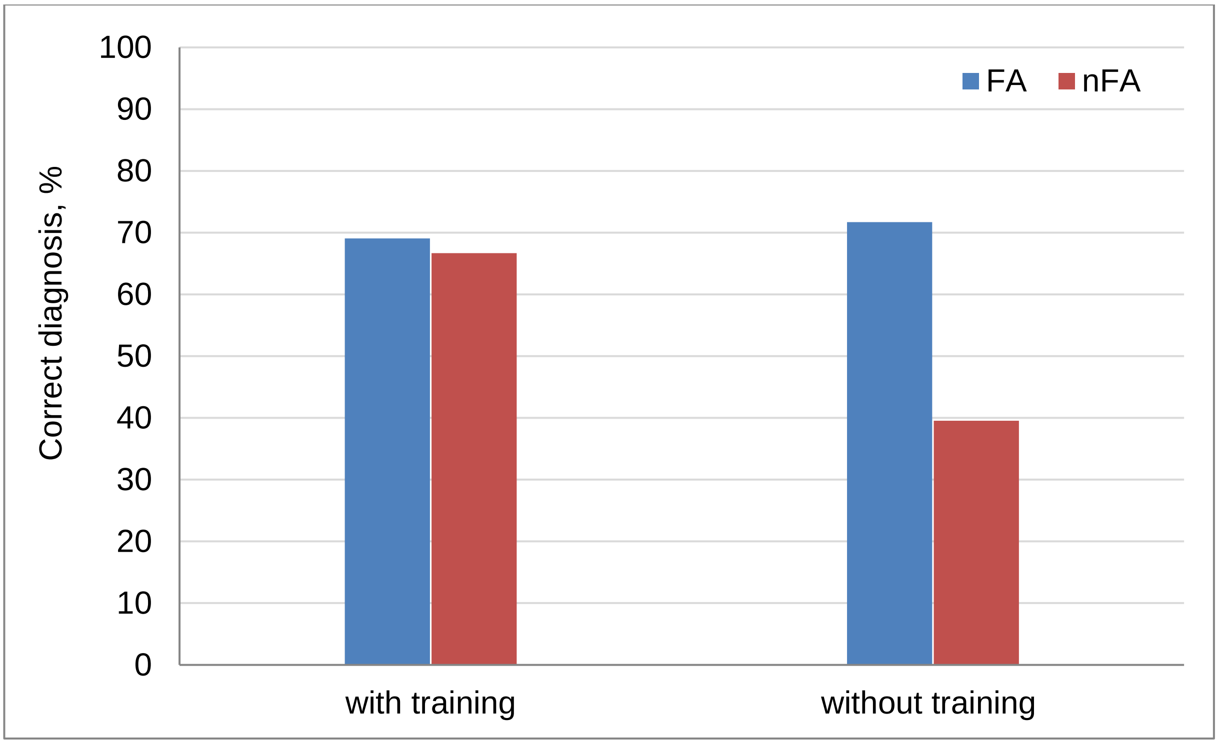

Figure 3.14 Percentage of correct diagnosis by FA (with training (n=5), without training (n=35)) and nFA (with training (n=3), without training (n=117)) respondents with and without training. Statistical analysis is provided in Appendix 6.

3.4.18 Effects of respondents' farm locations in ability to diagnose crop problems.

Generally, the FA respondents performed better in pest and disease diagnoses than nFA respondents in A'Suwaiq, Al-Musanah, Barka, Sohar, Saham and Al-Khabora Wilayats (Figure 3.15, $P < 0.001$, Appendix 6). For instance, FA respondents of A'Suwaiq Wilaya (where the majority of FA and nFA respondents were located) were able to achieve 68.5% correct diagnoses in comparison to 42.7% for nFA respondents. In Al Musanah Wilayat, the difference between FA and nFA respondents in correct diagnoses ability was greater. The FA respondents were able to identify 75% of the pests and diseases while nFA respondents identify 36% only. Although the same trend was reported in Barka Wilaya where 77% of pests and diseases were identified correctly by FA respondents in contrast to 41% for nFA respondents, but caution need to be taken in consideration due to lower numbers of FA respondents. The mean percentage of correct diagnoses of FA respondents in Saham Wilaya was greater (100%) than it was for nFA respondents (32%). In Al Khaborah Wilaya, FA respondents performed better (73%) than nFA respondents (32%) in correct identification of crop problems.

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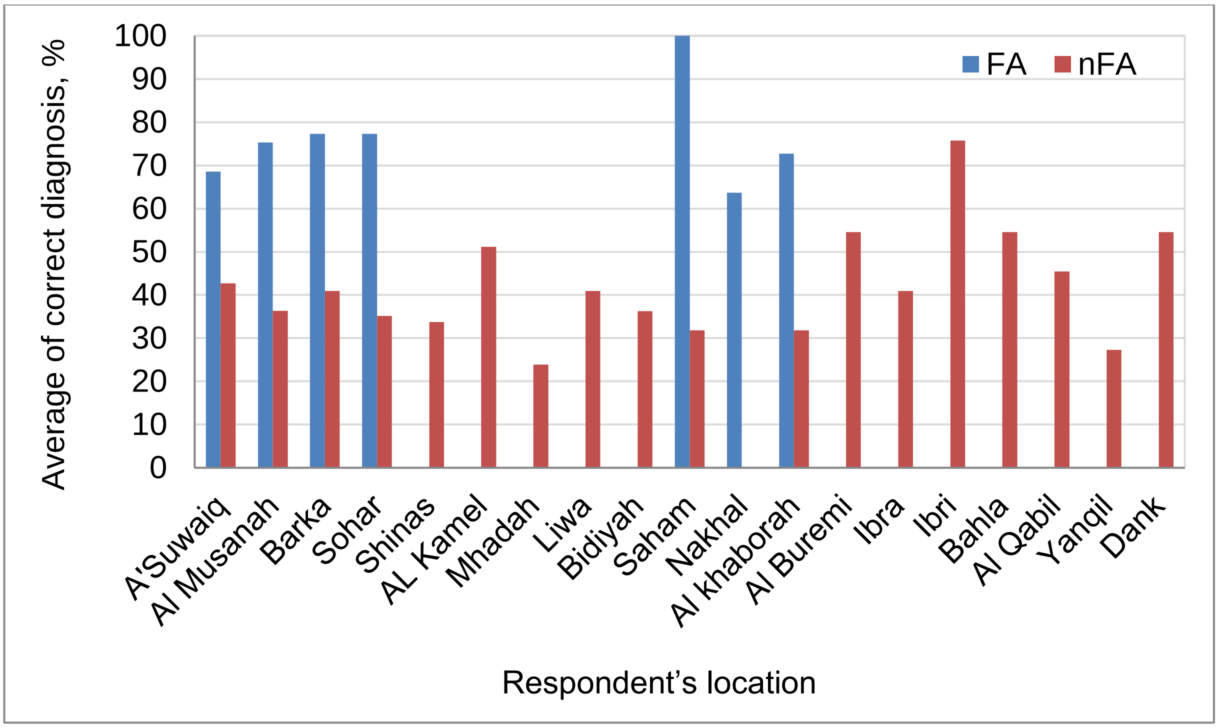


Figure 3.15 Mean percentage of correct identifications of pests and diseases by FA (n=40) and nFA (n=120) respondents based on their location. Statistical analysis is provided in Appendix 6.

3.4.19 Association of farm size on the ability of respondents to identify crop problems.

There was a positive effect of farm size in FA respondents' ability to diagnose the common pests and diseases. As the farm size increased from 0.1 to 19.9 ha, the mean percentages of correct diagnoses of FA respondents increased from 59 to 100% (Figure 3.16; $P< 0.001$, $R^{2\ =}$ 0.902, Appendix 13, A) in comparison to a less marked increase from 35 to 47% for nFA respondents (Figure 3.16; $P< 0.001$, $R^{2\ =}$ 0.533, Appendix 13, B). The association with farm sizes above 20 ha fluctuated for both groups.

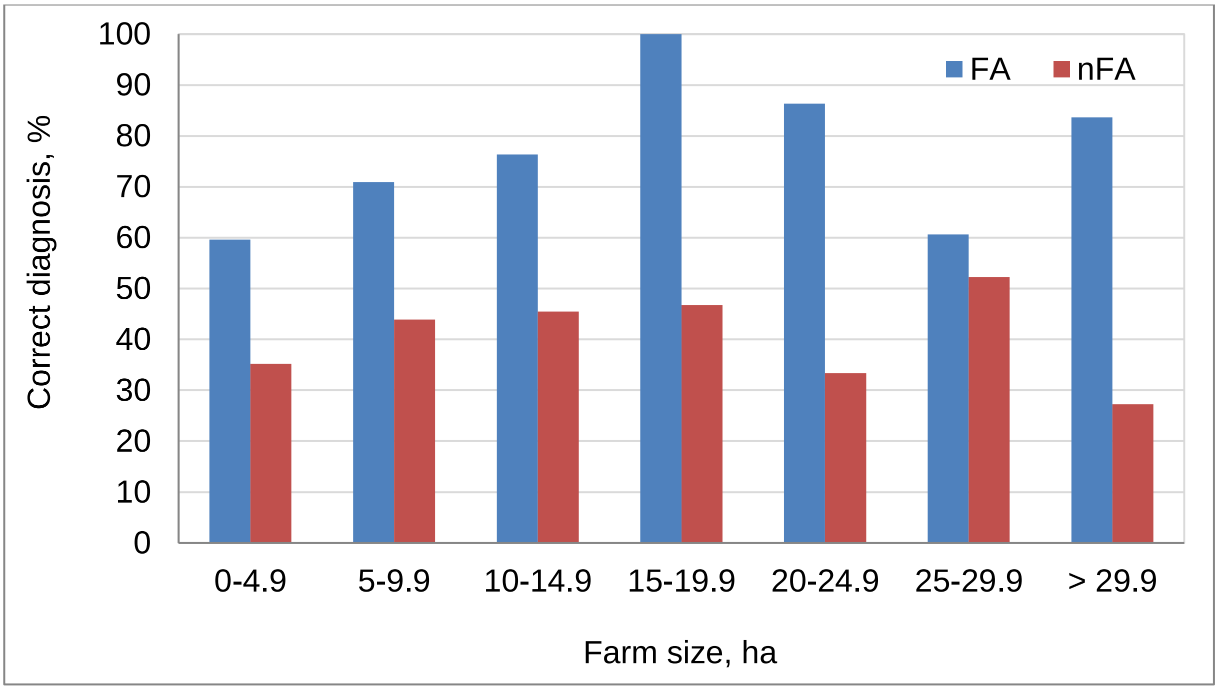


Figure 3.16 Mean percentages of correct diagnosis of pests and diseases by FA (n=40) and nFA (n=120) respondents based on their farm sizes. Statistical analysis is provided in Appendix 6.

3.4.20 Effects of sources of advice on the ability of respondents to identify crop problems.

The FA respondents who used retailers as a main source of diagnostic advice achieved 72% of correct identification in comparison to 37% of nFA respondents using the same source (Figure 3.17, $P< 0.001$, Appendix 6). Around 74% of correct identifications were achieved by FA respondents who sought advice from MAFWR in contrast to 56% by nFA respondents but caution need to be taken in consideration due to low number of FA (6) respondents in comparison to nFA (17) respondents. Using another farmer's advice to diagnose common crop problems improved diagnostic ability of FA respondents (67%) while it did not support nFA respondents very much (36%). There was no single respondent from FA who exclusively accessed the internet for diagnostic help while only one nFA respondent did and, interestingly, he was able to identify all the pests and diseases (Figure 3.17).

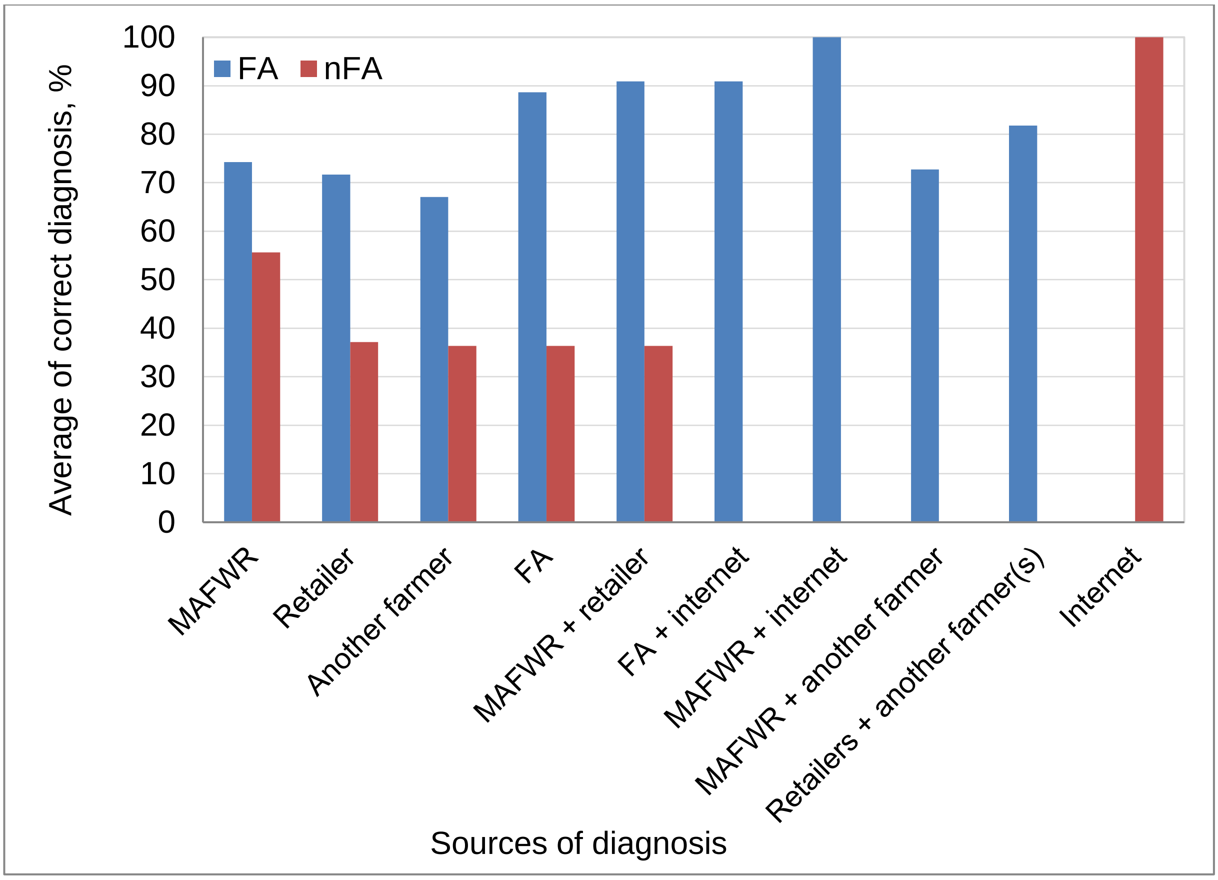


Figure 3.17 Mean percentages of correct diagnoses by FA (n=40) and nFA (120) respondents based on the source of diagnostic advice. Statistical analysis is provided in Appendix 6.

3.5 Discussion and conclusion

3.5.1 Discussion

The main objective of the surveys reported in this chapter was to investigate whether the FA and nFA farmers differed in their ability to diagnose the common pests and diseases of their vegetable crops and to attempt to explain any differences observed. As hypothesised, FA respondents could generally diagnose pest and diseases better than nFA respondents. There were significant differences between the rank averages of correct diagnoses within each group and between two groups in their capability to identify the eleven pests and diseases. During the survey, it was observed that nFA respondents were facing difficulties to name the problems and around 25 of them said that while they knew the problem, they did not know its name. A similar problem has been reported in other research (Kiros-Meles and Abang, 2008, Abang et al., 2014 and Adam, Sindi and Badstue, 2015). In addition, some nFA respondents mentioned that they sought the advice of nearest pesticide retailer after showing them the infested or infected sample when they had been unable to identify it. Normally if the farmer grows the same crop for several years, one might expect that he or she should have known the causal agents of the problem by experience and how to tackle that specific problem. However, some of nFA respondents only grew a small number of crops and so they may not be familiar with problems on other crops included in the survey. To address this issue, the data were also analysed for problems occurring on the crops they grew. It was still the case that some respondents within the nFA group were unable to diagnose common problems attacking the crops they were growing.

Many of FA and nFA respondents confused mites and thrips. This fact showed low ability of both groups' respondents to identify thrips, which mainly infests sweet pepper. Since farmers in the same area exchanged knowledge, incorrect identification might have spread between farmers as wrong information which may lead to improper control strategy such as a wrong pesticide selection and application. To some extent, misidentification and incorrect choice of pesticide may explain the excessive use of pesticides in vegetable crops as will be demonstrated in chapter 4.

However, respondents were not only varying in ability to identify pests and diseases attacking their crops, but they also differed in understanding crop protection steps and strategies. Many respondents identified the pests and diseases from the photos attached on the pesticide labels. The questions, therefore, arise, (1) do they also know the correct control strategy or pesticide and (2) do they know how to apply the pesticides safely and at the correct dose? For those who were unable to identify their common problems, it is important to recognize that they might simply be unable to name the problem and so they need to be asked the same two questions. Clearly, the most important issue going forward is that growers are helped to apply the correct products safely and at the correct times and doses to their crops.

There are many factors that could affect respondents’ answers for the identification of pests and diseases. These include age, experience, education level and training (Mendesil et al., 2016). In this study, the status of the respondents was found to be one of the determinate factors. Owners and tenants were the most frequent respondents for FA while tenants and foreman constituted the majority of respondents for nFA. This showed the importance of tenants in diagnosing the crop problems in the vegetable farms in the country. Tenants constituted 45% of the total respondents for both groups (FA and nFA) and only 5% of the respondents were owners for nFA group showing that nFA farms were managed mainly by tenants but not by the owners, and the tenants or foremen were mainly taking the decisions for all farming practices. There was a significant difference between FA and nFA respondents. Owners and tenants of FA revealed better diagnostic ability than owner, tenants, foremen and workers of nFA. Owners of nFA also were better able to identify problems than tenants and foremen from the same group. These results reveal the need to study the factors or reasons that drive the landlords or the farmland owners to rent their farms and what are the differences in farming practices including pest and disease diagnosis, proper pesticide selection and application and the health and safety issues between farms managed by owners and those managed through letting or sub-letting. Diagnosis of pests and diseases is a very critical point in choosing a crop protection strategy. Owners were taking this responsibility within FA farms for those either managed by them or rented to a second party but in nFA farms, retailers, tenants and foremen were responsible for diagnoses. This means that in nFA farms, owners had very little responsibility for diagnosis of crop problems.

In such cases, the contract conditions between the farmland owner and the tenant determine the responsibility of all farming activities practiced in the farm including crop protection measures. This situation may raise a need for some government involvement in such contracts to ensure outbreaks of some pests and diseases are controlled and so that losses in vegetable production do not affect the economy since most of the vegetables are produced for export.

Although diagnosis was not correlated significantly with FA respondents' age as with nFA, still age and experience sometimes supports a farmer's decision making in different farming practices (Mendesil et al., 2016). Respondents who were not members of the FA showed a slightly higher level of agriculture experience than FA respondents probably because they were on average slightly older than the FA respondents. In dealing with pesticides however, FA respondents had more experience than nFA respondents. The experience of FA respondents was supported by other factors such as education, training and active knowledge diffusion between the FA members which may have improved their ability to diagnose the problems correctly (Al Zadjali et al., 2013). Experience is clearly an important factor that affects the respondents' diagnostic ability. There was a significant difference between FA and nFA respondents for correct diagnosis. This may occur due to accumulation of knowledge over time and interactions of respondents with different experienced farmers, retailers and agriculture companies who diffuse the correct information and give support to farmers for long periods. FA respondents were relatively more educated than nFA as was found by Al Zadjali et al. (2014). Education may help farmers to improve their ability to identify crop problems by reading different types of books, leaflets, or journals or getting access to the information sources such as internet which assists them to perform the farming practices in proper way. Farmers who are less educated may not be able to read or to get access to different information sources, so they depend on other farmers or retailers and usually they are not able to learn the practices from information media or sources. Nevertheless, there was a positive and significant correlation between correct diagnosis and education level for both FA and nFA respondents. The correlation was clearer within nFA respondents due to high proportion of respondents who were uneducated or had very low education level. Similar findings were also reported in Oman and elsewhere

(Adjrah et al., 2013, Al Zadjali et al. 2014, Khan and Damalas, 2015, Rijal et al. 2018).

Moreover, knowledge diffusion or sharing between respondents of each group could be another supportive factor that may help farmers groups to improve farming practices (Noy and Jabbour, 2020). In the farming communities where the education level and experience are very low, training becomes imperative. As shown in Table 2.3, there was a dearth in the training programmes for both groups FA (12.5%) and nFA (2.5%) and none of these training programmes was in pest and disease diagnosis. It is therefore argued that there is a need to develop specific training programmes in crop protection including a module on identification of major or common pest and diseases attacking vegetables crops (Hashemi et al., 2009 and Wright et al., 2016). These will not only help farmers to diagnose common problems but also avoid the misleading by other sources of incorrect identifications and it will improve crop protection strategies that farmers are practicing. Training is an important element to improve farmers' abilities to diagnose different pest and diseases attacking crops. Much research has demonstrated the importance of training to farmers especially in low education level areas and for farmers with less experience (Wright et al., 2016). The number of training programmes that FA and nFA respondents attended were very low. Sometimes the area where respondents are located could have certain effect on farmers' knowledge and implementation.

In some areas where the farmers had good experience or had attended training programmes and education levels were high, they could share these information and help improve each other's knowledge and awareness of more sustainable farming practices including the ability to diagnose economic pests and diseases. The surveys were performed in the seven governorates of the northern part of Oman and about 30% of the respondents were from Al Batinah south and north. In formulating recommendations, it was relevant to find out if the location of the respondents was affecting their ability to diagnose the crop problems. However, the only difference noted was between FA and nFA respondents in the same wilaya (e.g Al Musanah) and between wilayats within Al Batinah south and north governorates; there was no evidence of a difference between respondents from Al Batinah governorates and other governorates.

In addition to the knowledge diffusion within same area or region which may assist the farmers to diagnose pests and diseases properly, retailers were found as the main source of identification support and advice for both FA and nFA respondents with a relatively higher dependence of nFA on retailers than FA. These findings raise questions on retailers' knowledge and perceptions in pest and disease diagnosis, pesticide selection and application and health and safety of pesticide applications. These questions are addressed in Chapter 6.

Most of the FA and nFA respondents' farms were small-scale (<10 ha) which was also reported earlier (Kotagama and Al-Farsi, 2019). There was strong correlation between farm size and ability of FA and nFA respondents to diagnose crop problems. The FA respondents with large farms were better able to diagnose crop problems than nFA respondents with small farms but there was no effect of farm size between respondents in each group. As the farm size increases, more vegetable crops may be being grown and more pests and diseases are encountered which consequently could mean larger-scale farmers would be better able to diagnose the different pests and diseases attacking the crops they grow.

Pesticide retailers were the major source of diagnosis advice for both FA and nFA respondents. Nonetheless, nFA respondents who depend on retailers on diagnosis revealed lower ability to diagnose the crop problems correctly (<40%) which may ascribe to misunderstanding or ignorance of nFA respondents to the retailers' diagnosis explanations. Although there were many governmental extension directorates and centres in the Wilayats covered by the survey, but there was little evidence that these directorates or centres are helping the farmers with crop protection advice. Clearly the reasons for the lack of advice need to be identified and tackled. This could reveal that the farmers from same associations are sharing knowledge and experience of different farming practicies (Al Zadjali et al., 2013). These findings revealed the weakness of the official sources such as government extension services and also disclosed that the FA did not help the farmers in the diagnosing process. The weakness in government extension services was also evident by the small number of training programmes that FA and nFA respondents had attended. The study revealed the need to improve government extension services to recover the gap between farmers and governmental bodies.

3.5.2 Conclusion and recommendations

Hypothesis: FA members identify pests and diseases more accurately than non-FA members.

The objective of this chapter was to study the capability of farmers to identify major vegetable pests and diseases attacking their crops and factors associated with their diagnostic ability. The results showed that:

1. FA respondents revealed a better ability to recognize different problems affecting their crops than nFA respondents.
2. Factors associated with the better diagnostic ability of FA respondents include:
    a. Their status - 40% of FA were farm owners compared to only 5% of nFA; 10% of nFA were ordinary farm workers compared to none in that category for FA,
    b. Education level - FA respondents were better educated, 83% having reached grade 7 or higher whereas 48% of nFA respondents were either uneducated or only an elementary education level,
    c. Farm size - 75% of FA owned large farms (≥ 4.9ha) whereas 41% of nFA owned small scale farms (≤ 4.9ha).
3. Factors less clearly associated with the better diagnostic ability of FA respondents include:
    a. Their age – 82.5% of FA respondents were aged 20-50 years in comparison to 72% of nFA respondents.
    b. Agriculture experience – FA respondents had slightly longer agriculture experience (65%) than nFA respondents (59%).
    c. Training – Although both groups obtained little training, FA respondents obtained more training (12.5%) than nFA respondents (2.5%).
    d. Location - All of FA respondents (100%) and most of nFA respondents were from Al Batinah South and North governates.
    e. Sources of diagnostic advice – Retailers were the major source of advice for FA (67.5%) and nFA (77.5%) respondents.

Based on the findings, the hypothesis was accepted.

3.6 Recommendations

1. Designing crop protection programmes including pest and disease diagnosis that are damaging the economic crops and cause severe losses to vegetable production. Separate programmes may need to be run for FA, nFA farmers and retailers to improve their awareness, knowledge and skills to diagnose the economic pests and diseases.

2. Improve the technical capabilities of governmental extension officials by performing training programmes.

3. Study the decision-making process of pests and diseases diagnosis within farms since significant numbers of the respondents who were responsible for decision making (FA and nFA, but especially nFA), could not identify the common pests and diseases during the survey.

4. There is a need to attach a leaflet or brochure to pesticide labels in other languages than Arabic so that it can be readable by farmers who do not understand Arabic.

5. Allow nFA farmers to join the FA as members to improve their technical information of crop protection including diagnosis.

3.7 References

Abang, A. F., Kouamé, C. M., Abang, M., Hanna R. and Fotso A. K. (2014) 'Assessing vegetable farmer knowledge of diseases and insect pests of vegetable and management practices under tropical conditions', *International Journal of Vegetable Science*, 20, pp. 240-253.

Abhilash, P. C. and Singh, N. (2009) 'Pesticide use and application: An Indian scenario', *Journal of Hazardous Materials*, 165, pp. 1-12.

Adam, R. I., Sindi, K. and Badstue, L. (2015) 'Farmers' knowledge, perceptions and management of diseases affecting sweet potatoes in the lake victoria zone region, Tanzania', *Crop Protection*, 72, pp. 97–107.

Adjrah, Y., Dovlo, A., Karou, S. D., Eklu-Gadegbeku, K., Agbonon, A., de Souza, C. and Gbeassor, M. (2013) 'Survey of pesticide application on vegetables in the littoral area of Togo', *Annals of Agricultural and Environmental Medicine*, 20, pp. 715-720.

Akter, M., Fan L., Rahman, M. M., Violette Geissen V. and Ritsema, C. J. (2018) 'Vegetable farmers' behaviour and knowledge related to pesticide use and related health problems: A case study from Bangladesh', *Journal of Cleaner Production*, 200, pp. 122-133.

Al Adawi, A. O., Al Jabri, R. M., Deadman, M. L., Barnes, I., Wingfield, B. and Wingfield, M. J. (2013) 'The mango sudden decline pathogen, *Ceratocystis manginecans*, is vectored by *Hypocryphalus mangiferae* (Coleoptera: Scolytinae) in Oman', *European Journal of Plant Pathology*, 135, pp. 243-251.

Al Mawaali, Q. S., Al Sadi, A. M., Al Said, F. A, Deadman, M. L. (2013) 'Etiology, development and reaction of muskmelon to vine decline under arid conditions of Oman', *Phytopathologia Mediterranea*, 52, pp. 457-465.

Al Sadi, A. M., Al Said, F. A., Al Kaabi, S. M., AL Quraini, S. M., Al Mahmooli, I. H. and Deadman, M. L. (2011) 'Occurrence, characterization and management of fruit rot of immature cucumbers under greenhouse conditions in Oman', *Phytopathologia Mediterranea*, 50, pp. 421-429.

Al Sadi, A. M., Al Ghaithi, A. G., Al Fahdi, N. and Al Yahyai, R. (2014) 'Characterization and pathogenicity of fungal pathogens associated with root diseases of citrus in Oman', *International Journal of Agriculture and Biology*, 16, pp. 371-376.

Al Zadjali, S., Morse, S., Chenoweth, J. and Deadman, M. (2013) 'Disposal of pesticide waste from agricultural production in the Al-Batinah region of Northern Oman', *Science of the Total Environment*, 463-464, pp. 237-242.

Al Zadjali, S., Morse, S., Chenoweth J. and Deadman, M. (2014) 'Factors determining pesticide use practices by farmers in the Sultanate of Oman', *Science of the Total Environment*, 476-477, pp. 505-512.

Bulmer, M. (2004) ‘Questionnaires’, V.1. Thousand Oaks, CA: Sage Publications. Grasswitz, T. R. (2019) ‘Integrated pest management (IPM) for small-scale farms in developed economies: Challenges and opportunities’, *Insects*, 10(6).

Hesse-Biber, S. N. (2016) ‘The practice of qualitative research’, 3rd Edition, Sage Publications Inc., USA.

Galletta, A. (2013) ‘Mastering the semi-structured interview and beyond: From research design to analysis and publication’, New York University Press, USA.

Gurr, G. M., Liu J., Johnson, A. C., Woruba, D. N., Kirchhof, G., Fujinuma, R., Sirabis, W., Jeffery, Y. and Akkinapally, R. (2016) ‘Pests, diseases and crop protection practices in the smallholder sweetpotato production system of the highlands of Papua New Guinea’, *PeerJ*, 4:e2703.

Gwet, K. L. (2011) ‘The practical guide to statistic: Basic concepts, methods and meaning. Application with MS Excel, R, and OpenOffice Calc. (2nd ed.)’, Advanced Analytics LLC., USA.

IWMI, (2007) ‘Water for food, water for life: a comprehensive assessment of water management in agriculture’, Earthscan and Colombo. International Water Management Institute, London

Khan, M. and Damalas, C. A. (2015) ‘Factors preventing the adoption of alternatives to chemical pest control among Pakistani cotton farmers’, *International Journal of Pest Management*, 61, pp. 9-16.

Kiros-Meles, A. and Abang, M. M. (2008) ‘Farmers’ knowledge of crop diseases and control strategies in the Regional State of Tigrai, northern Ethiopia: Implications for farmer-researcher collaboration in disease management’, *Agriculture and Human Values*, 25, pp. 433-452.

Kotagama, H. B. and Al-Farsi, H. (2019) ‘Impact of the domestic labor market on sustainability of agriculture in Oman’, *Journal of Agricultural and Marine Sciences*, 23, pp. 24-28.

Leon, A. C., Davis, L. L. and Kraemer, H. C. (2011) ‘The role and interpretation of pilot studies in clinical research’, *Journal of Psychiatric Research*, 45, pp. 626-9.

Likert, R. (1932). ‘A technique for the measurement of attitudes’, *Archives of Psychology*, 22(140): 55.

Lyman, O. R. (1993). ‘An Introduction to statistical methods and data analysis’, CA: Duxbury press, USA.

Mendesil, E., Shumeta, Z., Anderson, P., Ramert, B. (2016) ‘Smallholder farmers’ knowledge, perceptions and management of pea weevil in north and north-western Ethiopia’, *Crop Protection*, 81, pp. 30-37.

Noy, S. and Jabbour, R. (2020) ‘Decision-Making in local context: Expertise, experience, and the importance of neighbours in farmers’ insect pest management’, *Sociologia Ruralis*, 60, pp. 3-19.

Oerke, E. C. (2006) 'Crop losses to pests', *Journal of Agricultural Science*, 144, pp. 31-43.

Oerke, E. C. and Dehne, H. W. (2004) 'Safeguarding production - Losses in major crops and the role of crop protection', *Crop Protection*, 23, pp. 275-285.

Okolle, N. J., Afari-Sefa, V., Bidogeza, J., Tata, P. I., Ngome, F*. A.* (2016) 'An evaluation of smallholder farmers' knowledge, perceptions, choices and gender perspectives in vegetable pests and diseases control practices in the humid tropics of Cameroon', *International Journal of Pest Management*, 62, pp. 165-174.

Rijal, J. P., Regmi, R., Ghimire, R., Puri, K. D., Gyawaly, S. and Poudel, S. (2018) 'Farmers' knowledge on pesticide safety and pest management practices: A case study of vegetable growers in Chitwan, Nepal', *Agriculture (Switzerland)*, 8(1).

Ruttan, V. W. (2005) 'Scientific and technical constraints on agricultural production: Prospects for the future', *Proceedings of the American Philosophical Society*, 149, pp. 453-468.

Schreinemachers, P. et al. (2017) 'Too much to handle? Pesticide dependence of smallholder vegetable farmers in Southeast Asia', *Science of the Total Environment*, 593–594, pp. 470-477.

Shabani, F., Kumar, L. and Al Shidi, R. H. S. (2018) 'Impacts of climate change on infestations of Dubas bug (*Ommatissus lybicus* Bergevin) on date palms in Oman', *PeerJ*, 6:e5545.

Wang, W., Jin, J., He, R. and Gong, H. (2017) 'Gender differences in pesticide use knowledge, risk awareness and practices in Chinese farmers', *Science of the Total Environment*, 590–591, pp. 22-28.

Wright, D., MacLeod, B., Hammond, N. and Longnecker, N. (2016) 'Can grain growers and agronomists identify common leaf diseases and biosecurity threats in grain crops? An Australian example', *Crop Protection*, 89, pp. 78-88.

Chapter 4. Farmers' knowledge, attitudes and practices when selecting and applying pesticides to some vegetable crops in Oman.

4.1 Summary

Indiscriminate use of pesticides leads to adverse implications to human and environment. Whitefly and thrips were more frequently reported within FA than nFA respondents' farms. Results revealed a more appropriate selection of pesticides by FA respondents compared to nFA. In addition, FA respondents were more likely to use correct doses of pesticides (59%) in comparison to nFA respondents (33%). Pre-harvest intervals (PHI) were also better observed by FA respondents (45%) in comparison to nFA (21%) although the fact that less than half were following the correct PHI is concerning. The results indicated that age, education level, pesticide experience, training, farm size and source of advice did not affect pesticide selection, but affected pesticide application and adherence to the PHI. When measuring spatial variability of pesticide application in three specific fields, none of the farmers were consistently complying with recommended application rates. The rates they used fluctuated between 94% lower and 222% greater the recommended rates, i.e. from approx. 1/16th to over twice the recommendation. One potential factor which might influence under- or overdosing pesticides is the quality of the products. Most of the pesticides used by nFA were non-patented, "me-too" products and the quality of these products may be lower than the original manufacturer's specification, compromising their effectiveness. If so, there is a need for quality checks during the registration process. Heterogeneity of pesticide deposition confirmed the variation and extensive use of unsatisfactory pesticide application methods such as with a hand-held hose and a high-pressure spray, which indicates an urgent need to review the whole spraying system to ensure its suitability to control various pests and diseases attacking vegetable crops. Introducing new pesticide application technologies is imperative to mitigate the abuse of pesticides. Planning of training programs for governmental crop protection or extension services officials, retailers and farmers is essential to improve pesticide handling and pest management scheme in the country.

Keywords: Pesticides, dose rate, pre-harvest interval, spraying, spatial variability.

4.2 Introduction

The tremendous increase of pesticide uses in the last decades to control various insects and diseases attacking vegetable crops has led to serious concern for the Oman government. The problem has become worse due to the lack of certified pesticide application companies that are supposed to be eligible to do the applications. Many of the farms' respondents (see chapter 3) were illiterate or less educated and they did not understand the application instructions stated on the label which may lead, in some cases, to overuse and overdoses. No certified scheme of pesticide application is implemented in the country which increases the needs for legal framework. The situation has led the government's Ministry of Agriculture, Fisheries Wealth and Water Resources (MAFWR) to make laws and regulations to manage the pesticide movement, handling and use in the country and to stop the illegal practices related to pesticide use.

4.2.1 Pesticide Management Strategy

4.2.1.1 Pesticide Law and Executive Regulations

The main legal basis for use of pesticides in Oman was promulgated on June 25, 2006 by Royal Decree no 64/2006 called "Pesticide Law". It was introduced to regulate the whole cycle of pesticides in the country. The law comprises fourteen articles stating the general framework of the pesticides. Detailed information of the pesticide law was stated in the executive regulations issued by Ministerial Decision no 41/2012 on February 12, 2012. Executive regulations comprise nine chapters with thirty-six articles and eight attachments (Table 4.1). It regulates registration, containers and label specifications, importation and exportation, handling, manufacturing, pesticide use, maximum residue limits, disposal, advertising and inspection of pesticides. The attachments contents include the following[4]:

[4] In an email to the author, Hanan Al Zakwani (MAFWR) acknowledged for the provision of information.
[4] Hanan Al Zakwani, personal communication, 24 January 2021.

Table 4.1 Attachments of executive regulation of pesticide law.

Attachment No.	Title
1	Fees
2	Pesticide toxicity classification (WHO)
3	Pesticide importer and exporter store specifications
4	Pesticide importation permit requirements
5	Pesticide (shop/showroom) store specifications
6	Active ingredient importation requirements
7	Pesticide manufacturing license requirements
8	Disposal of empty containers

4.2.1.2 Banned and restricted active ingredients

In 2007, the Ministry of Agriculture, Fisheries Wealth and Water Resources issued Ministerial Decision no. 194/2007. The decision banned 133 active ingredients and restricted 33 others. This decision was updated by including the new banned and restricted pesticides list within the Ministerial Decision no. 41/2012 which adds 131 banned and 30 restricted active ingredients. Both lists were updated further through the Gulf Cooperative Council Countries (GCC) technical team in 2016 and the final list specified 57 restricted active ingredients and 284 banned ones. The lists are, however, still not approved officially by the GCC leaders. Inclusion or withdrawal of any active ingredients was decided based on the toxicity evaluation reports issued by the World Health Organization (WHO), Environmental Protection Agency (EPA) and International Agency for Research on Cancer (IARC)[5].

[5] In an email to the author, Hanan Al Zakwani acknowledged for the provision of information.
[5] Hanan Al Zakwani, personal communication, 24 January 2021.

4.2.1.3 Pesticide registration

Before 2012, there was no registration scheme in Oman for the pesticides imported and used in agriculture to control pests, weeds and diseases. The firm that applied for an import permit only had to meet a few requirements including registration certificate of the products in the country of origin, physical and chemical analysis from certified laboratory, technical data sheet, label and active ingredient sample with method of analysis. After 2012, the MAFWR issued the pesticides executive regulations no. 41/2012 which included registration of pesticides. In 2013, a Pesticides Registration Committee (PRC) was established by Ministerial Decision no. 8/2013 which included members from MAFWR, Ministry of Regional Municipality and Water Resources, Ministry of Environment and Climate Affairs, Ministry of Health, Ministry of Trade and commerce and Muscat Municipality. The PRC started the implementation of a registration program for all imported and locally produced pesticides. There were 119 protection products registered up to December 2020, comprising 35 insecticides, 41 fungicides, 12 insecticide/acaricide, 4 acaricides, 3 nematicides, 13 rodenticides, 4 fumigants, 3 biocides and 4 herbicides[6].

4.2.1.4 Pesticide importation

Pesticide quality is one of the major factors that determine the efficacy of any pesticide in controlling the targeted problem. To date, there is no quality control laboratory in Oman so all the pesticides manufactured or imported are not subjected to any types of check for their quality. The local authority depends on the certificate of analysis issued by the country of origin. The MAFWR is establishing a new pesticide quality control laboratory, but it is not yet operational. The efficacy of any pesticide depends on the compliance of the product to the global specifications certified by Food and Agriculture Organisation (FAO) for the chemical and physical properties. In many countries around the world, farmers are searching for cheapest pesticides to reduce production costs, but normally the cheapest pesticides are also of lower quality. This may account for the overuse of pesticides in some parts of the

[6] In an email to the author, Hanan Al Zakwani acknowledged for the provision of information.
[6] Hanan Al Zakwani, personal communication, 24 January 2021.

world and in Oman as well. Furthermore, chemical companies selling the pesticides pay incentives to promote their use through advertising and sales promotions which may create a bias in favour of their products (Tisdell et al., 1984).

4.2.2 Pesticide selection

The first step in performing strategy control to any plant problem is the correct diagnosis of the problem. If the farmer decides to spray pesticides, then the second step should be selecting proper pesticide. When selecting pesticides, farmers believe more in pesticides that are more effective against the targeted pests and diseases (Cameron, 2007 and Ngowi et al., 2007, Hashemi and Damalas, 2011, Schreinemachers et al., 2017, Mengistie, 2017). The farmers believed that the best pesticides are those which possess an instant kill action (knock down) towards the targeted problem. According to Sharifzadeh et al. (2018), if a pesticide does not affect and quickly kill the targeted pests, it may be less used by farmers or replaced by another more effective pesticide. Selection of the proper pesticides to control a particular organism may have different perceptions from one country to another and from one farmer to another. There are many factors which may influence the decisions made by the farmers. These include status, age, education, experience, training, farm size, source of advice and prices of products. In a study held in Nigeria, it was found that age, education level, farming experience, price of grains were significantly affecting the decision of farmers to use organic or inorganic pesticides (Adejumo et al., 2014), but the study does not show the selection of pesticides by farmers and the role of pesticide sellers in the selection process. It was also reported that the selection of a specific pesticide to be used in controlling vegetable pests and diseases was based on their own experience in pesticide usage (Halimatunsadiah et al., 2016). Moreover, Damalas et al. (2006) found that most farmers rely on pesticide sellers and one third of them rely on their own experience when deciding to use pesticides. They also reported that only 6% of Greek tobacco growers rely on the information stated on label.

4.2.3 Pesticide application

The implications of pesticides for people and the environment depend on pesticide application process. Farmers should follow the instructions stated on the pesticide container label. However, it was reported that not all farmers follow the application instructions on the labels and there are many factors affecting farmer's decisions (Al Zadjali et al., 2014; Khan and Damalas, 2015; Gautam et al., 2017 and Sun et al., 2019).

4.2.3.1 Dose rate (dilution rate)

The key point in pesticide usage efficacy is the adherence to the recommended dose rate. The implications of higher or lower doses may include selection for pesticide resistance, failure to control the problems, environmental pollution and loss of money and efforts. In India, farmers in one study did not know the accurate doses of the pesticides they should apply to achieve cost-effectiveness (Abhilash and Singh, 2009). According to Jha and Regmi (2009), farmers apply pesticides at rates four times higher than recommended and hence indiscriminate applications of pesticides are increasing (Atreya et al., 2011 and Sharma, 2015). In a study held in Bangladesh to assess the pesticides use pattern amongst farmers, it was demonstrated that 20% of the farmers either use more or less than the required quantity (Sabur and Molla, 2000). In Greece, it was found that 46 of tobacco growers exceeded the recommended dose rates mentioned on the pesticide labels (Damalas et al., 2006). The misuse of pesticides has also been reported in other countries. For instance, in China, it was demonstrated that farmers overused and underused pesticides when controlling pests, diseases and weeds (Zhang et al., 2015a and Zhang et al., 2015b). This result was also confirmed by Sun et al. (2019) who found that misuse of pesticides sometimes occurred in 100% of pesticide applications. They ascribed that to weak extension services, lack of pest management knowledge, misleading information and the absence of pest and disease forecasts. Khan and Damalas (2015) reported that around half of the cotton farmers in Pakistan showed a tendency toward pesticide overuse by spraying higher quantities of pesticides than the label rate. In Thailand, it was also reported that vegetable farmers overused and underused pesticides to control various vegetable and fruit pests and diseases (Schreinemachers et al., 2011, Sangchan et al., 2012 and Grovermann, et al., 2013). In Kenya, It was reported that 27% of vegetable growers had overdosed pesticides leading to a waste of pesticides, phytotoxicity, resistance and pest resurgence (Macharia et. al., 2013). Ethiopian vegetable farmers believed that higher pesticide doses meant better control of pests and based on this misconception they were applying pesticides at higher rates than recommended (Mengistie et al., 2017). In Armenia, vegetable growers sprayed the same crop 20-40 times with the same pesticides in every season (Tadevosyan et al., 2013). In Cameroon, an even worse scenario was reported where the tomato farmers were applying pesticides which did not have labels on the containers showing the correct dose rates (Tandi et al., 2014). In Oman, there is a dearth in the literature on farmers' practices on pesticide applications. However, the frequencies of pesticides used in FA and nFA farms were studied by Al Zadjali et al. (2014). They found that there was no difference between FA and nFA owner respondents on the frequency of pesticide use but there was a difference between workers of both groups. Nevertheless, the study did not assess the perceptions of the farmers on pesticide dose rate applications.

4.2.3.2 Pre-harvest interval (PHI)

Overuse of pesticides and ignorance of PHI leads to various implications including the accumulation of the pesticide contaminants in plant parts including edible fruits and vegetables as residues (Qin et al., 2016 and Jallow et al., 2017). The best way to eliminate the problem of pesticide residues might be to require the farmers to follow the PHI stated clearly on the pesticide label. In a study conducted to vegetable growers in Malaysia, it was found that farmers usually ignored the recommended PHI and the farmers continued spraying their crops close to harvest (Halimatunsadiah et al., 2016). The same attitudes were observed in a total of 86 vegetable and fruit growers in Egypt; the author confirmed that none of the respondents followed the PHI stated on the pesticide labels (Saleh Abbassy, 2017). Moreover, Shrestha et al. (2010) reported that more than half of the vegetable growers in Nepal pick the vegetables 0-4 days after pesticide application, resulting in increased pesticide residues in the produce. Tadevosyan et al. (2013) demonstrated that around 7% of the Armenian vegetable farmers were found to harvest the fruits on the same day of pesticide application, some others waited 1-5 days after application and only 18% were found waiting for 20 days after spraying. In Vietnam, it was reported that 25-43% of the vegetable farmers waited for only 4-6 days instead of the PHI of 7-14 days and above when they use crop protection products (Tan, 2021).

4.2.3.3 Factor affecting farmer's perceptions and implementation of pesticide regulations and label guidance

Reported misuse of pesticides worldwide might be due to many factors such as age, experience, education, training, location, farm size and source of advice (Gautam et al., 2017). The level of the effect of these factors may vary depending on various social, economic and cultural conditions or circumstances (Abbassy, 2017). For example in China, older farmers were found to apply more pesticides than younger ones (Yang et al., 2019). The excessive use of pesticides by older farmers appeared to be associated with market profit and governmental regulations. The effect of education level on the overuse or underuse of pesticides seems, however, to be contradictory. Some studies showed that there was a positive correlation of education on Pakistani farmers' adopting safer pesticide practices (Khan and Damalas, 2015) while other studies performed in Bangladesh revealed either negative (Rahman, 2016) or no association as it was reported in Nepal (Rijal et al., 2018). In Nepal, Shrestha et al. (2010) illustrated that most (n=30) of the vegetable growers (93.3%) did not receive training at all in the use of pesticides. Similar results were reported for vegetable growers in Ethiopia where 78% out of 220 farmers had not participated in any training on pesticide use or handling (Mengistie et al., 2017). Due to knowledge diffusion amongst farmers in the same district, the same (unsafe) handling practices of pesticides including excessive dose rates could be normal. Unsafe handling of pesticide was also reported for 425 vegetable growers in the Meru Central district in Kenya (Macharia et al., 2013). Gautam et al. (2017) illustrated that training in the application of integrated pest management (IPM) was found to improve the use of pesticides in the vegetable farms in Bangladesh such that after training, farmers reduced the amounts of pesticides used per spray. There is a scarcity of literature on the association of farm size with the intensity of pesticide usage. Nonetheless, some studies indicated that in China, more pesticides were used on larger farms than on smaller farms (Zhu and Wang, 2021).

3.2.3.4 Source of advice.

Sources of pesticide application advice or reputable advisory services are expected to help determine the accuracy of pesticide application by the farmers. There are many sources of information, farmers may use to select and apply the pesticides including labels, government extension services, the internet, social media, private shops (pesticide retailers or sellers) and neighbouring farmers. Governmental extension services are not-for-profit organizations, but pesticide retailers make profits through advising and selling the pesticides to farmers. It was observed in Oman that the weakness of the extension services was forcing farmers to seek advice from pesticide retailers (Al Zadjali et al., 2013). In Nepal, it was demonstrated that round 84% of vegetable growers use pesticide dosages as per the advice of pesticide retailers instead of following the label recommendations (Rijal et al., 2018). It was demonstrated that employees of pesticide retailers have no technical background and the information received from them was misleading in many instances. Furthermore, a conflict of interest between provision of services and product selling may be exhibited by the service providers from private for-profit companies. According to Okonya and Kroschel (2015), some potato growers in Uganda applied fungicides up to 18 times and insecticides up to 12 times per cropping season although the authors did state the recommended number of treatments per season. They concluded that when it came to the doses of pesticides to use, farmers in the southwestern and eastern highlands relied mostly on their own previous experience and reading instructions on the pesticide label (38% and 55%, respectively) while in Lake Albert Crescent, most farmers (50%) relied on pesticide retailers. Tandi et al. (2014) indicated that tomato farmers in Cameroon preferred to obtain information on pesticide use from private pesticide sellers in their areas. In Ethiopia, around 85% of vegetable farmers were getting pesticides from small shops, none of whom used scaled weighing or volume measuring equipment (Negatu et al., 2016).

4.2.3.5 Assessment of spraying method and sprayers used

In China, it was reported that spraying efficiency depends on the type of sprayers that farmers use and the conditions of sprayers (Xiao et al., 2020). All the interviewed farmers in Ghana indicated that they cleaned their spraying equipment after pesticide use by rinsing with water (Kwakye et al., 2019). According to Abhilash and Singh (2009), the majority of Indian farmers used locally manufactured sprayers which were least durable, developed cracks and leaked quite frequently. The authors concluded that the sprayers were not properly maintained, cleaned and handled. Cost and availability of capital could be the main determinant of using modern and more advanced sprayers. According to Mengistie et al. (2017), lack of money was driving the vegetable-growing smallholders in Ethiopia to use knapsack instead of motorized sprayers.

4.2.3.6 Pesticide resistance

The frequent and excessive use of the same pesticide or of pesticides with the same mode of action is likely to lead, over a period of five years, the pest, weed or disease to evolve resistance against that particular pesticide or probably also cross-resistance to pesticides with the same mode of action (Buhler, 2021). In Nepal, it was demonstrated that around half of the respondents used same pesticides repeatedly during the same season, resulting in high costs of new insecticides, lack of diversity of pesticide active ingredients and poor understanding of resistance management leading to pesticide resistance (Rijal et al., 2018). Many reports have indicated that control of various pest and diseases was challenged by resistance development against insecticides (Bass et al., 2015) and fungicides (Lucas et al., 2015). According to Gisi and Leadbeater (2010), managing resistance is important strategy for effective and efficient use of pesticides. However, Khan and Damalas (2015) suggested that to prolong the effectiveness and usefulness of pesticides, their sustainable use may play a key role in successful pest management.

4.2.3.7 Using pesticide mixtures

Farmers believed that mixing of pesticides provide better effect (Konradsen et al., 2003). Halimatunsadiah et al. (2016) indicated that most of the vegetable growers in Malaysia prefer to use pesticide mixtures. In Ethiopia, although pesticide labels do not contain any information on mixing and compatibility of active ingredients, Mengistie et al. (2017) reported that most of the vegetable growers (87%) mix two pesticides before application while 13% use both mixtures and single pesticides. They concluded that farmers believed that mixtures of pesticides would help them save time and labour and were more efficient in pest and disease control. Nearly two-thirds of the farmers applied pesticides in mixtures. It was common for farmers to combine a contact and systemic fungicide plus an insecticide within a single tank mixture to reduce costs for pesticide applications. Reducing costs associated with spraying was also the main reason for combining more than one pesticide among potato farmers in Ecuador (Sherwood et al., 2005) and vegetable farmers in Tanzania (Ngowi et al., 2007). Moreover, Schreinemachers et al. (2017) found that a round 80% of the pesticide applicators agreed with the statement that mixing pesticides makes them more effective.

4.2.3.8 Application rate (amount of pesticide/ unit area)

Proper pesticide application rate is important to deliver the accurate amount of the pesticides to the plants, reducing adverse environmental impacts on non-target organisms and non-crop areas and ensuring uniform and sufficient coverage. Miranda-Fuentes et al. (2015) found that the increase in the application volume raised the mean deposit and percentage coverage, but decreased the application efficiency, spray penetration, and deposition homogeneity. It was reported that drift spray is affected by many factors including droplet size, cross wind speed, driving speed and release height (Hassen et al, 2014). In a study conducted to assess different spraying techniques (mounted axial fan air-assisted sprayer and tower or selective sprayer) and application rates, tower sprayers showed better pesticide coverage than conventional type but there was no significant effect of elevated application rates in comparison to lower rates in terms of spraying quality and efficiency (Sedlar et al., 2013). According to Nath et al. (2017), the use of a proper spraying technique and the correct nozzles would improve the efficiency of pesticide application. However, Gil et al. (2007) suggested the use of tree row volume calibration method instead of conventional calibration procedure to improve pesticide application efficiency, deposition, penetration, drifts and save amount and cost.

4.2.3.9 Quality control (pesticide quality)

Pesticide efficiency against the target pests and diseases depends on the quality of the active ingredient and its compliance with the approved specifications by FAO. New active ingredients are more effective than old or non-patent active ingredients due to the higher level of physical and chemical specifications to fulfil FAO specifications. Respondents from nFA group were prone to use off-patent pesticide products in comparison to FA respondents who preferred to use branded new active ingredients formulated by major manufacturing companies worldwide (Al Zadjali et al., 2014). Pesticide producers can be divided in two main groups: basic producers who own the intellectual property rights of the active ingredients and the second group comprises formulators or generic or “me too” producers who formulate older, off-patent active ingredients. Using such off-patent products against pests and diseases could lead to excessive use of these pesticides and consequently increase the likelihood of human exposure, environmental pollution and resistance problems. There has been a significant increase in pesticide usage in Oman in recent decades and the available statistics reported by MAFWR showed that the amount of imported pesticides rose from 200 to about 800 tonnes between 2009 and 2020[7]. Although pesticides are considered as one of the major agricultural inputs, still there are many concerns worldwide on the quality of the pesticides used in crop protection programmes. There are questions on the efficacy and quality of the “me too” or generic pesticides used to control different pest and diseases. Generic or “me too" pesticides were reported to be less effective against the targeted pests and diseases in comparison to patented products (Durmusoglu et al. 2008 and Pauluhn and Ozaki, 2015).

[7] In an email to the author, Hanan Al Zakwani acknowledged for the provision of information.
[7] Hanan Al Zakwani, personal communication, 24 January 2021.

4.2.3.10 Pesticide application spatial variability

Most of the people who physically apply pesticides in the field in Oman are immigrant workers. They may have a lower level of education and may not be able to read or understand the instructions on the pesticide labels regarding pesticide applications and safety precautions before, during and after application. They frequently apply pesticides without calibration using stretcher-mounted high-pressure sprayers with inconstant pressure (Thacker et al., 2000). According to Wise et al. (2010), a precise combination of sprayer type, water volume and pesticide was needed to optimise efficacy against key insect pests and fungal diseases of vineyards in the eastern United States. In Bangladesh, it was reported that damaged nozzles, however, may produce a higher flow rate than the allowed limits of as specified in nozzle inspection regulations (Subr et al., 2015). Nuyttens et al. (2007) showed that nozzle type and size have an important effect on droplet size as well as on velocity spectra. They found that droplet size and droplet velocity spectra were correlated to each other and they allowed drift to affect the quantity and distribution of the deposit on the target. Moreover, some nozzle types were found to be affecting droplet size and the pesticides' physical properties while some manufacturers were not suggesting that growers needed to select the proper nozzle types to increase efficacy and reduce spray drift (Ferguson et al., 2015).

Despite the widespread use of 'spraying' approaches to pesticide application and the acknowledged importance of achieving an even distribution of pesticide in the field, very few studies of spatial variability of pesticide applications have been carried out. Bateman (2017) demonstrated a threefold variation in deposition rate over 6m when a five-nozzle boom was swept round an arc of 180° during application of pesticides to lowland (paddy) rice in Vietnam. The calibration of the nozzle inclination showed significant impact on the uniform deposit distribution of chemical sprayed on hedgerow vineyard (Pergher, 2004). Variation over the whole field was not, however, assessed. Some studies comprised measurements of material flow rates through the sprayer nozzle and were used to document the extent to which variable rate applications were achieved on a zonal basis within fields. The type of sprayer may contribute to that spatial variability of pesticide application. In a study performed to evaluate the spatial variability of the quality of the pesticide applications using a cannon sprayer, they concluded that the sprayer was not able to maintain uniformity for any of the variables evaluated including coverage but the authors did not mention the nozzle sizes used in the study (Silva et al., 2015). They also demonstrated that wind gust enhanced the drifts to opposite direction. Another study was conducted in New Zealand to assess deposition from conventional and novel spray delivery systems in a potato canopy and demonstrated that the treatments with novel technologies gave better pesticide coverage to the underside potato leaves than conventional boom sprayer (Roten et al., 2013). In a comparison of seven different sprayers, Dekeyser et al. (2014) demonstrated that type of sprayer influenced spray deposition and distribution greater than changing fan speed gear or adjusting the air deflector. The study reported in this chapter investigated the actual spatial variability in application rate across small vegetable fields - a problem which needs to be addressed before variable rate applications could even be contemplated.

However, the aims of this study were also to ascertain the appropriateness of pesticide selection and application and to understand the possible factors affecting farmers' decision and their willingness to utilise practices which increase the risk of developing resistance and to document the spatial variability of pesticide deposition in vegetable crops in Oman and to quantify and visualise the extent of unintended variable deposition rates. Gathering all results, the study was designed to answer the question if farmers (FA and nFA) can select the appropriate pesticide to control pests and diseases and whether the farmers applied pesticide according to the labels' recommendations?

4.3 Materials and Methods

4.3.1 Farmer's association and non-farmers association survey

The surveys of FA and nFA were performed as described in Chapter 2. Surveys covered 40 respondents from FA members and 120 respondents from nFA. Thirteen questions in section five "Pesticide use and application" in relation to pesticide selection and application including dose rate or dilution rate (amount of AI(s) in water) and pre-harvest intervals (PHI) were addressed to the respondents. The respondents were also investigated for their understanding of resistance (Appendix 2). For pesticide selection and application, the comparison reference was pesticide local labels that are approved by the local authority (MAFWR) and followed and used by the farmers including crops, target pests or diseases, dilution rate (±10% the label rate) and pre-harvest intervals (±1day the label interval).

4.3.2 Focus group

The use of focus groups allows the gathering of important qualitative data, information and feedback from groups on specific topics. It is frequently used in social studies such as marketing to test consumer behaviour towards products or services. The discussion must be planned in advance of a meeting and the number of participants might vary from (6 to 12) or even more. Each participant in the focused group is allowed and even encouraged to give an opinion on the topic discussed or to respond to questions posed by the researcher. It is a quick, easy and low-cost process of extracting information from participants but must be managed carefully to avoid problems such as a dominant position being taken by senior participants over others, and the more convoluted methods of data analysis required. Thirteen FA farm owners participated in the group discussion (Figure 4.1). Together they represented the pre-eminent vegetable producers in Oman. Their agricultural experience varied between fifteen and twenty years. The discussion was held at the FA's head office in A'Suwaiq wilaya at Al Batinah north (Figure 4.1, Chapter 4). The discussion was managed by the researcher in a way that allowed all farmers to express their opinions and experience on the topics discussed and to avoid domination by a single farmer by insisting on rotation of input.

Figure 4.1 Group discussion on pesticide selection and application of FA (n=13). The discussion was held in the farmers' association head office at A'Suwaiq in 15 February 2017.

The researcher started with an introduction about the topic and then explained the main objectives of the discussion and guaranteed anonymity of the participants to give the farmers more confidence to express their attitudes, perceptions and feelings towards the questions discussed. Six open-ended questions (themes) were semi-structured (Appendix 19) with the ensuing discussion being conducted in Arabic. The time allowed for discussion was 90 minutes. The questions were designed to understand the farmers' attitudes in terms of pesticide application and their approach to deal with resistance against some pesticides. There was no limited time given to each question or to any farmer and all the farmers were free to talk about their experience as required. The participants were also given the chance to talk to each other during the discussion. The discussion was managed not just by asking questions but also by discussing farmer’s queries as they arose. This encouraged farmers to explain their perceptions of pesticide use in more detail. The discussions were recorded using a mobile recorder and subsequently transcribed for detailed analysis.

4.3.3 Assessment of application rate (amount of a.i./unit area)

The measurement of application rate is very important to ensure that each plant receives the recommended amount of pesticide at each application. The application rates in all fields were measured based on farmer’s normal practices. In all fields, the farmers mixed the pesticides with water in 200L containers. The drums were placed in the centre of the plots and filled with water up to 200L. The pesticides were added to the drums and mixed manually. High pressure pumps (3.37 KW) were used to deliver the sprays which were directed manually from the hoses via a spray guns attachment. On most farms the foremen or a designated worker executes the spraying process. While spraying, the applicator walks between the planting rows to spray the plants individually until the total amount of pesticide solution in the drum is finished. In cases where surplus pesticide mix remains in the drum, the pesticide applicator usually sprays it onto the plants in the next row or plot. During this study, the application rate of pesticides was measured on five farms, two FA farms from Al Musanah (1) and A’Suwaiq (1) Wilayats and three nFA farms from Barka (2) and Al-Musanah (1) Wilayats (Table 4.5). The farms were selected based on the crops grown, farm area, spraying method, spraying machine and willingness of the farmers to cooperate and participate in the study. Prior to assessment, the researcher introduced himself and explained the main purposes of the study stated that anonymity of the participant would be guaranteed. All five selected fields were planted with tomato and the area of each field was measured by tape to determine the total area of each particular plot to be sprayed. Pesticide information: type, brand name, active ingredient(s), concentration, and table of use were recorded. The actual amount of pesticide solution used on each farm was also determined by measuring the amount of pesticide and water added to the mixing tank. After pesticide applications were completed, the amount of pesticide solutions left in the tanks were measured and the actual pesticide application rates per plot area were calculated and compared to the recommended rate stated on the pesticide label issued by the product manufacturer. If the application rate (ml or g/ha) was not written on the local label, the basic producer (i.e. the active ingredient manufacturer) of the pesticide was taken as a reference. The same process was repeated for all five fields.

4.3.4 Analysis of pesticide formulations (quality control test)

Six samples of the most commonly used pesticides from different farms were collected for active ingredient contents analysis. The selected active ingredients were widely used to control the major insects and diseases of vegetable crops. Two of them were fungicides (metalaxyl and copper oxychloride) and three were insecticides (emamectin benzoate, acetamiprid and deltamethrin) and the last one was mainly used to control mites (abamectin) but it can also be used as an insecticide to control other insects. The samples were collected randomly from some of the vegetable farm stores in March 2019 then labelled and sent to the Central Agricultural Pesticides Laboratory (CAPL) located in Cairo which belongs to the Ministry of Agriculture and Land Reclamation, Egypt. The samples were analysed in March 2019 using globally approved standard analytical methods. Metalaxyl content as the active ingredient in the wettable powder (WP) pesticide formulation product was determined using CIPAC method (365/WP/M/3, CIPAC E, p.128), and according to FAO specifications (FAO, 1992). The copper content in the copper oxychloride formulation was determined using thermometric titration method according to CIPAC 1, (44.0/3/M1/1.4, p.236) or (44.0/3/M2/1.4, p.238) and/ or CIPAC 1A, p.1170, according to FAO specifications (FAO, 1991). The principle is thermometric titration of copper with mixed sodium thiosulfate /potassium iodide titrant. Deltamethrin content as the active ingredient in emulsifiable concentrate (EC) formulation was assessed and determined using (333/EC/M2/3, CIPAC Handbook L, p.51, 2006) method according to FAO specifications (FAO, 2017). Since there are no FAO specifications for abamectin, acetamiprid and emamectin benzoate, basic producer's methods of content determination were used with support of other references. Reversed-phase high performance liquid chromatography (HPLC) was used to estimate and determine the concentration of the active ingredient component in these pesticides. Abamectin content was analysed using basic producer's method and other validated methods (Alexandre et al., 2016). Acetamiprid was analysed based on basic producer's method supported by other research work such as reported by Obana et al., (2002) and Lin et al., (2013). For emamectin benzoate formulation, basic producer's method of analysis was used and supported with other references (Rajasekaran et al., 2013).

4.3.5 Spatial variability assessment of pesticide application

4.3.5.1 Measurements of the amounts of pesticide deposited per unit area

In this experiment, to measure the spatial variation in pesticide application which affects the amount of pesticide deposited on a unit area, three farms were selected as one FA (farm 13 from the survey) and two nFA (farms no. 79 and 86 from the survey). The farms were located in Al Bedi area in Al Musanah (farm no. 13), A'Salam area in Barka (farm no. 86) and at Al Qurayhah in Barka (farm no. 79). The farms were selected based on the crop grown (tomato), method of pesticide application, type of spraying machine and cultural practices. Specific area of tomato plot was selected in each farm based on plant age and crop inter and intra spacing. However, all the cultural and pesticide use practices as usually performed by farmers were maintained. In each plot, the spatial pesticide application was measured by collecting the amount of pesticide deposited in a specific area. This was assessed by placing green plastic funnels (20cm diameter) in the field before pesticide application. Funnels were located within crop rows at the same height as the top of the plant canopy. The number of funnels per plot was 98 at Al Musanah (Al Bedi farm), 89 at Barka (A'Salam farm) and 100 at Barka (Al Qurayhah farm); the differences in numbers of funnels being dependent on the area of each plot and to facilitate a geostatistical sampling scheme using a basic grid but with nested sampling to capture both short-and long-range variability in application (Figure 4.2).

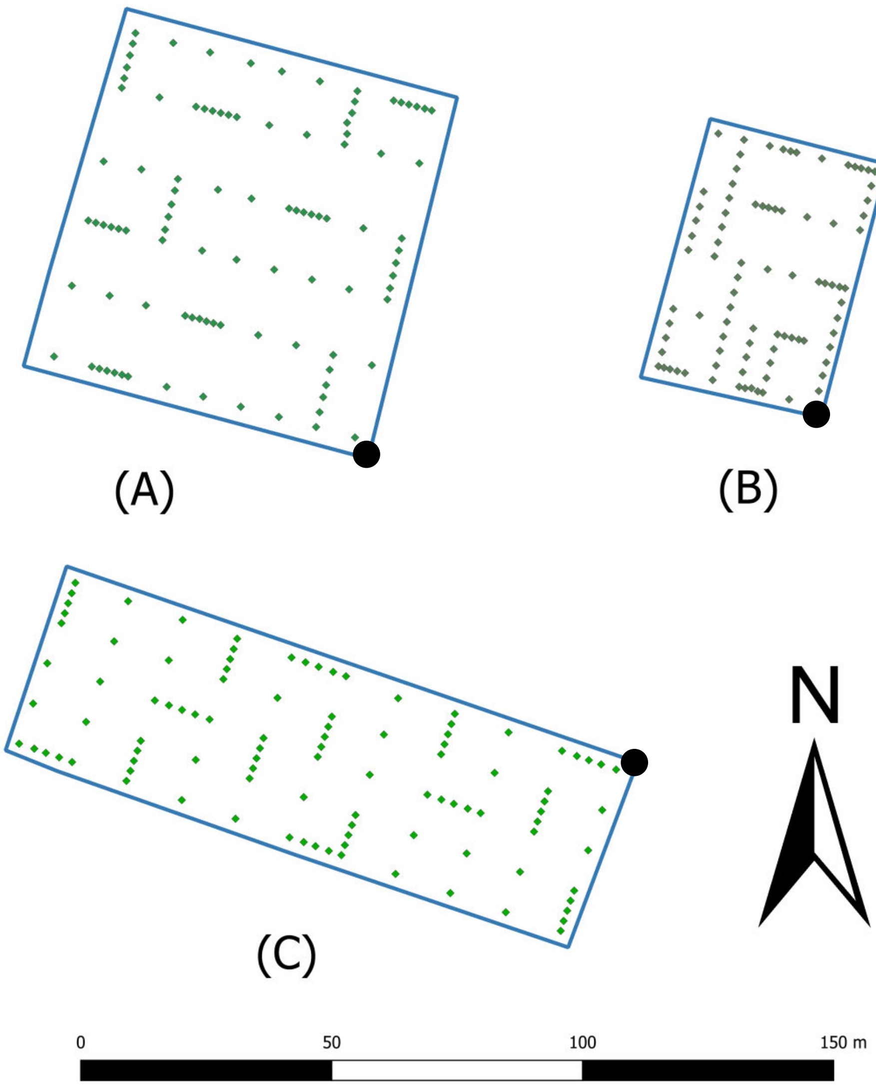


Figure 4.2 Sampling layout scheme of (A) Al Bedi field (n=98), (B) A'Salam field (n=89) and (C) Al Qurayhah field (n=100) using a basic grid design with additional nested samples. Reference point for each field is indicated by black circle at the corner of each field.

Funnels were connected to 300ml plastic bottles with masking tape to collect the pesticide. Funnel and bottles were fixed at the top of wooden stacks using binding wire to ensure stability during pesticide application (Figure 4.3). Bottles and funnels were numbered for identification purposes. After pesticide application, all funnels and bottles were collected and placed in a dry room at room temperature (25˚C) for weight measurements. Using a sensitive balance (0.01g accuracy), all bottles and funnels (having been weighed prior to pesticide application) were weighed after each application in order to obtain the weight of pesticide solution deposited. After removal of the masking tape, the bottles were sealed with a numbered cap and weighed while the funnels were weighed directly to avoid pesticide evaporation.

The funnel area was calculated as follows (diameter = 20 cm)

Circle Area (A)= $\pi/4 \times d^2$

A= $3.14/4 \times (20)^2 = 314.16\ cm^2$ or $0.0314\ m^2$

Figure 4.3 Funnel (20cm diameter) connected to a 300ml transparent plastic bottle to collect the pesticide deposition.

4.3.5.2 Application method

In all three farms, the farmers were using stretcher-mounted high-pressure sprayer (3.37 KW) with 3-400 kPa pressure targeting a flow rate of 8-10 L min^{-1}. The nozzle size was 1.3mm and the spraying width varied according to plant canopy and row spacing in each farm. In these experiments, the canopy width was around 80 cm with non-targeted spraying width not less than 50 cm from each side. Spraying was carried out as operators walked through the fields between the rows, but there was no calibrated walking pace, and variable speeds were observed.

4.3.5.3 Geostatistical analysis and mapping of the spatial variability of pesticide deposition

Because a sufficiently-accurate (i.e. to nearest 5 cm) geo-referencing instrument was not available, each sampling location was manually geo-located relative to a local reference point in each field. The latitude and longitude of this reference point was determined using 'Google Earth Pro' software (Figure 4.2). The location of each sample was then determined from this reference point using a tape measure and allotted x and y co-ordinates in metres. The longitude and latitude of the location of each sample could then be estimated.

Geostatistical analysis of the spray deposition data was carried out to determine the extent of spatially-correlated variation, using Matheron's method of moments to determine the variograms (Oliver and Webster, 2014; Mahmood and Murdoch, 2017) using GenStat 18th edition. Variogram models were selected using the smallest residual sum of squares (RSS). Interpolations and ordinary kriging were then used to map the spatial distribution of the amounts of pesticides deposited in each field using ArcGIS (v. 10.4) software.

4.3.6 Statistical analysis

Mean ranks for non-parametric data from the survey questionnaires, including Likert scale questions, were compared using either the Mann-Whitney U-test (for two groups) or Kruskal-Wallis analysis (for more than two groups) (Lyman Ott, 1993). Within Kruskal-Wallis analysis, where significant differences in mean rank were indicated ($P < 0.05$), individual mean ranks were separated by using the z-value for significance threshold (Gwet, 2011) implemented within Microsoft Excel. In all analyses $P < 0.05$ was taken to indicate significance in differences between rank averages or a significant correlation between variables. Data (percentage responses to questions) were analysed using Chi-square in statistics calculator (https://www.socscistatistics.com).

4.4 Results

4.4.1 Type of pest and diseases and size of problems

Most of the eleven pests and diseases were reported in FA and nFA respondents' farms. Whitefly (FA farms= 29%, nFA farms= 34%) and thrips (FA farms= 17%, nFA farms= 28%) were more frequently reported in nFA than in FA respondents' farms although the differences were not statistically significant (Figure 4.4). Downy mildew, damping off, late blight and leaf miners were more frequently reported in FA farms in comparison to nFA while early blight, spodopteran and aphids were more frequent in nFA farms. Although the Kruskal-Wallis analysis suggested there were significant differences between FA and nFA in the types and sizes of pest and disease infestations that existed in their farms ($P < 0.001$, Appendix 14), pairwise comparisons revealed that none of these apparent differences between FA and nFA was significant for a given pest or disease. Due to the small number of FA farms, comparison of the less frequently reported problems needs to be treated with caution.

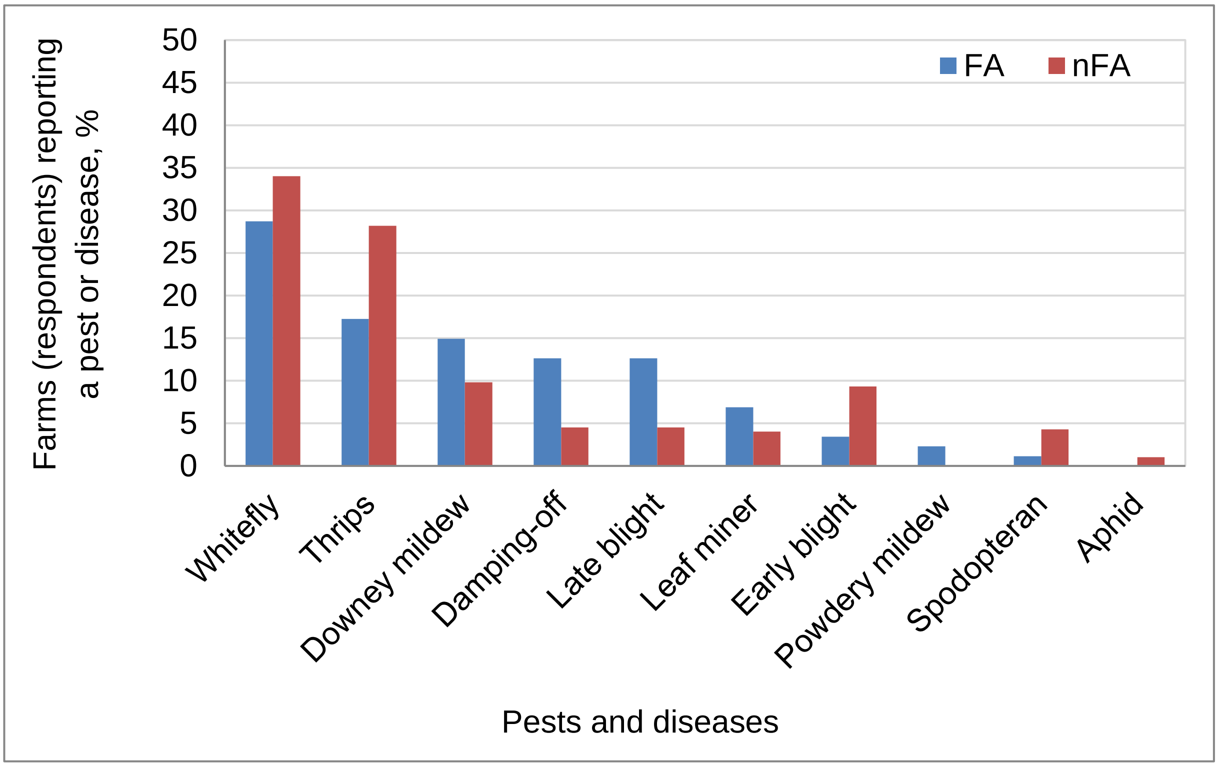


Figure 4.4 Percentage of farms reporting problems with ten pests and diseases for FA (n=40) and nFA (n=117) respondents. Analysis of the pairwise comparisons is provided in Appendix 14; no differences were significant.

4.4.2 Selection of correct and incorrect active ingredient

Generally, FA respondents selected the proper pesticides to control the eleven pests and diseases attacking their crops more frequently than nFA respondents (Figure 4.5). Most of the pesticides selected to control leaf miner (100%) and aphid (100%) by FA respondents were appropriate in comparison to 71.7% for leaf miner and 57.1% for aphid by nFA respondents. Higher proportions of FA respondents also selected the proper pesticides for whitefly (91.5%), early blight (83.3%) and thrips (75.9%) than nFA respondents. Nevertheless, nFA respondents performed slightly better than FA respondents when choosing pesticides for spodopteran (85.8% correct) and melon decline (76.2%) (Figure 4.5). Mann-Whitney analysis showed that there was no significant difference between FA and nFA respondents in the selection of the proper pesticides to control various pests and diseases reported at their farms ($P > 0.05$, Appendix 15). In addition, the Kruskal-Wallis mean rank analysis indicated no significant effect of age, education level, pesticide experience, training, location and farm size on the respondents' ability to recommend the proper pesticides ($P > 0.05$, Appendix 15). There was no significant difference between FA and nFA status. Nonetheless, the pairwise comparisons showed a significant difference between owners and tenants and between owners and workers within nFA group in their ability to select the proper pesticides ($P = 0.003$, Appendix 15). Workers revealed better performance followed by tenant and owners. However, some caution is needed due to the small numbers of nFA workers who participated in the survey (6) in comparison to owners (22), tenants (41) and foreman (48) of nFA respondents.

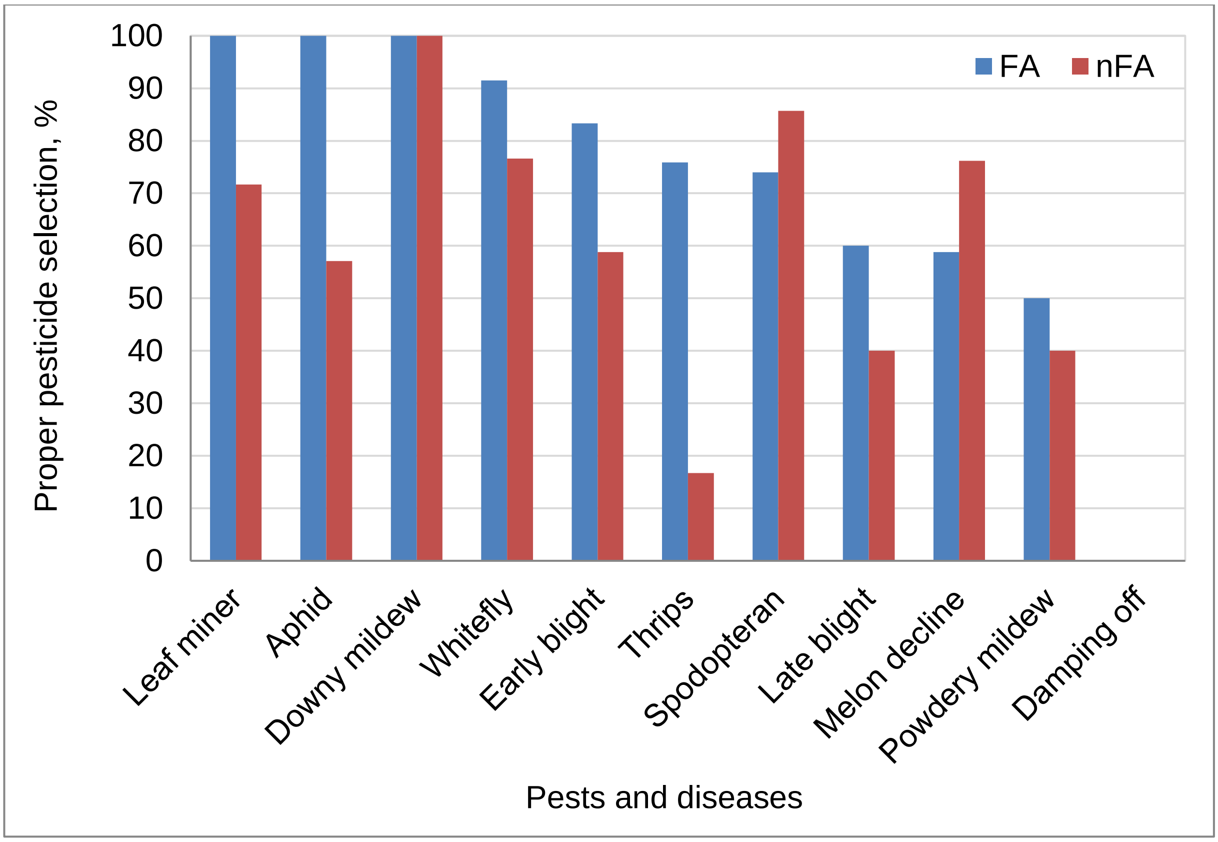


Figure 4.5 Percentage of appropriate pesticides recommended by FA (n=40) and nFA (n117) respondents to control leaf miner (FA, n=6 & nFA, n=33), aphid (FA, n=2 & nFA, n=12), downy mildew (FA, n=1 & nFA, n=2), whitefly (FA, n=86 & nFA, n=164), early blight (FA, n=45 & nFA, n=30), thrips (FA, n=22 & nFA, n=4), spodopteran (FA, n=37 & nFA, n=144), late blight (FA, n=30 & nFA, n=6), melon decline (FA, n=10 & nFA, n=16), powdery mildew (FA, n=2 & nFA, n=2) and damping-off (FA, n=0 & nFA, n=0). The values of n are the number of correct recommendations. Respondents could suggest more than one type of pesticides for each particular problem. The percentages should be treated with caution for pests and diseases with n<10. No differences were significant (Appendix 15).

Limiting the analysis to cases where a pest or disease had been ***correctly*** identified, most of FA respondents were able to select the proper pesticides to control leaf miner, aphid and powdery mildew (100% respectively) in comparison to nFA (Figure 4.6). Moreover, FA respondents revealed higher ability to select the proper pesticides to control whitefly (93.7%), early blight (83.7%) and thrips (85%) in comparison to (60.6%, 73.1% and 0% for nFA respondents. However, nFA respondents indicated higher proportions (93%) of appropriate pesticides to control late blight than FA respondents (64.3%). Although this analysis is restricted to cases where the problems had been identified correctly, none of the nFA respondents were able to recommend the appropriate pesticides to control thrips (Figure 4.6).

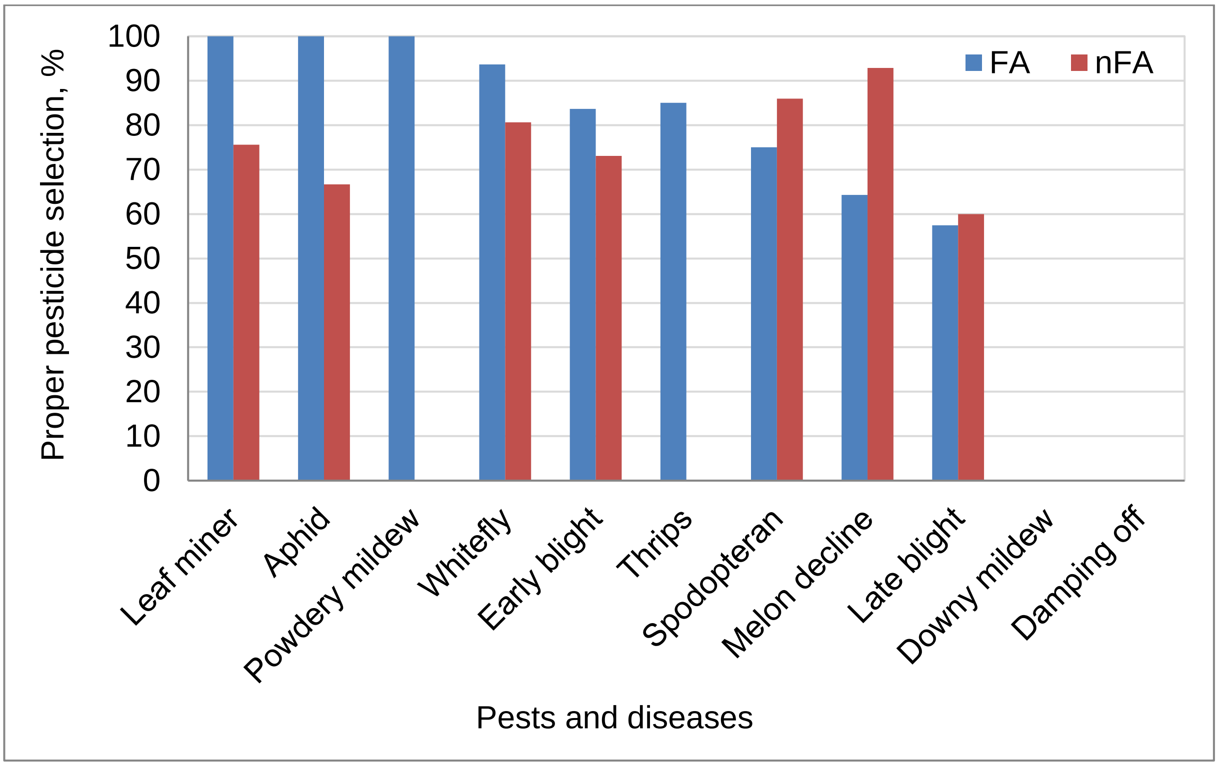


Figure 4.6 Percentage of appropriate pesticides recommended by FA (n=40) and nFA (n117) respondents who had first correctly identified the pest or disease to control leaf miner (FA, n=6 & nFA, n=31), aphid (FA, n=1 & nFA, n=2), powdery mildew (FA, n=2 & nFA, n=0), whitefly (FA, n=74 & nFA, n=154), early blight (FA, n=41 & nFA, n=19), thrips (FA, n=17 & nFA, n=0), spodopteran (FA, n=36 & nFA, n=141), melon decline (FA, n=9 & nFA, n=13), late blight (FA, n=27 & nFA, n=6), downy mildew (FA, n=0 & nFA, n=0) and damping-off (FA, n=0 & nFA, n=0) were correctly diagnosed. The values of n are the number of correct recommendations. Respondents could suggest more than one type of pesticides for each particular problem. The percentages should be treated with caution for pests and diseases with n<10.

In some cases, even when crop problems were diagnosed correctly, some of FA and nFA respondents suggested wrong pesticides (< 50%). In total, 54 and 90 pesticides were incorrectly recommended by FA and nFA respondents respectively to control the eleven pests and diseases. Improper pesticides suggested for controlling damping-off (100%) and late blight (40%) diseases by FA and nFA respondents were almost equivalent. However, improper pesticides selected by FA respondents to control melon decline (35.7%) and spodopteran (25%) were higher than nFA respondents (Figure 4.7). Nonetheless, nFA respondents selected more improper pesticides than FA to control thrips (100%), early blight (27%), whitefly (19.4%), leaf miner (24.4%) and aphid (33.3%) (Figure 4.7).

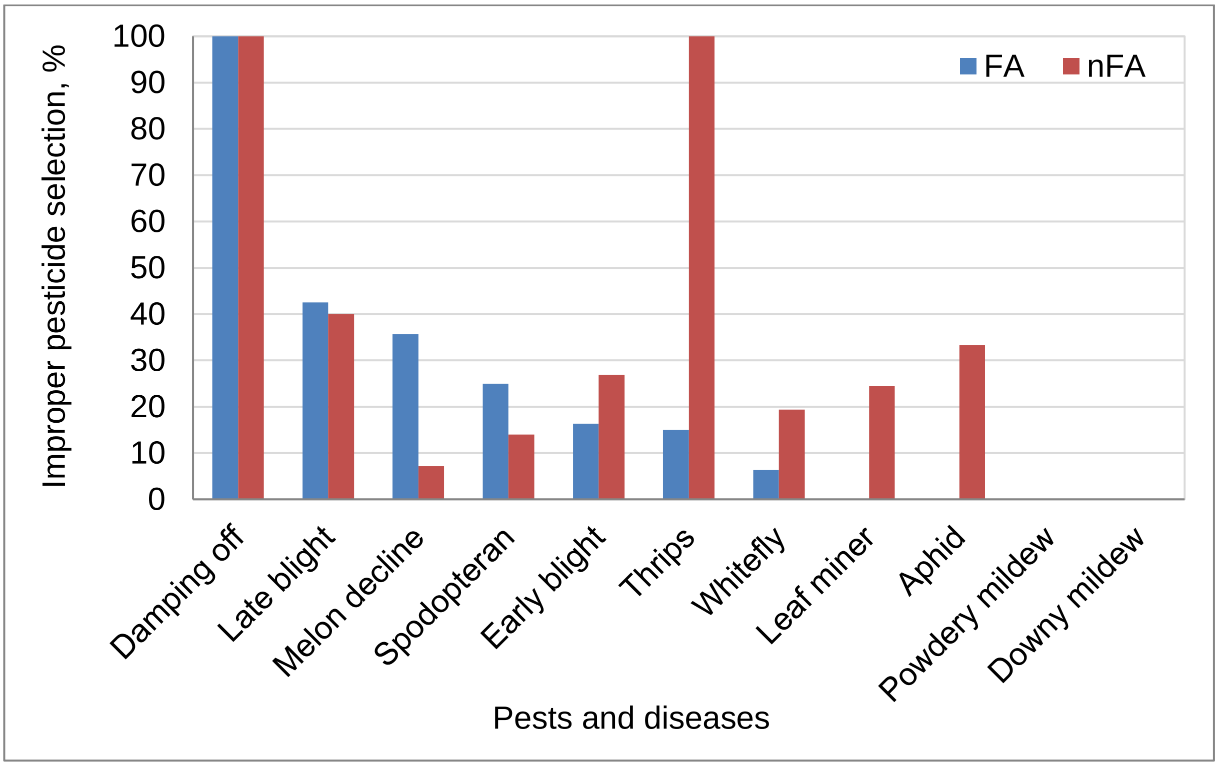


Figure 4.7 Percentages of inappropriate pesticides recommended by FA (n=40) and nFA (n=120) respondents when damping-off (FA, n=1 & nFA, n=1), late blight (FA, n=20 & nFA, n=4), melon decline (FA, n=5 & nFA, n=1), spodopteran (FA, n=12 & nFA, n=23), early blight (FA, n=8 & nFA, n=7), thrips (FA, n=3 & nFA, n=6), whitefly (FA, n=5 & nFA, n=37), leaf miner (FA, n=0 & nFA, n=10), aphid (FA, n=0 & nFA, n=1), powdery mildew (FA, n=0 & nFA, n=0) and downy mildew (FA, n=0 & nFA, n=0) were correctly diagnosed. The percentages should be treated with caution since most of the total selections of improper pesticides were less than 10.

4.4.2.1 Relationship between pest and disease identification and the selection of pesticide.

Correct pest and disease identification is the first step to proper selection of pesticides and this was evident in the significant positive correlation between correct problem diagnoses and proper selection of pesticides for both FA and nFA respondents (Figure 4.8) although the relationships were fairly weak, particularly for the nFA, indicating that other factors were involved.

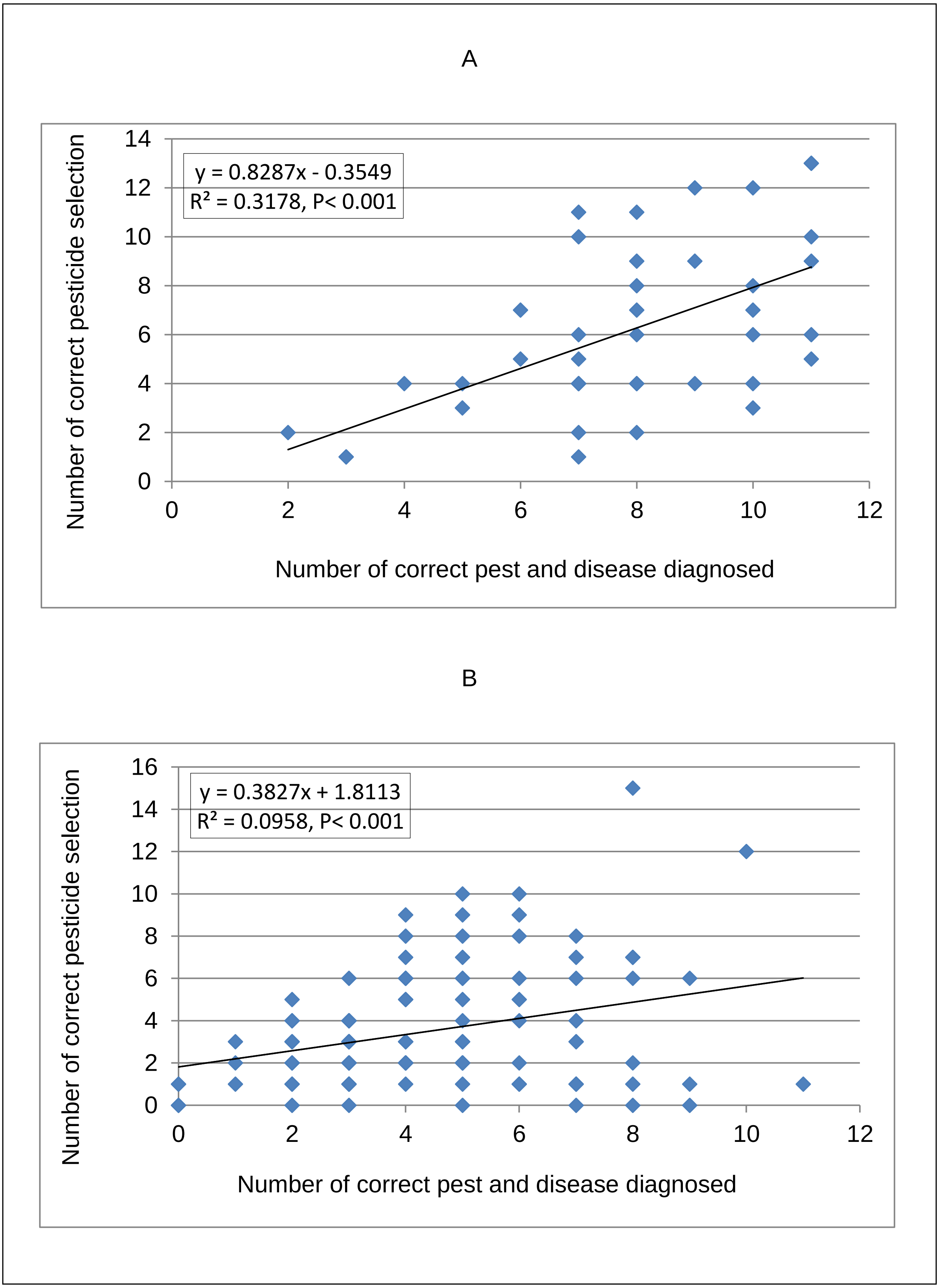


Figure 4.8 Relationship between correct diagnosis of pests and diseases and the selection of appropriate pesticide(s) for A) FA (n=40) and B) nFA (n=117) groups. Respondents could select more than one pesticide for particular problem. Linear regressions were fitted to estimate correlation.

4.4.2.2 Frequency and proportions of the active ingredients selected by FA and nFA respondents

A wide variety of active ingredients was used by FA and nFA respondents to control the various pests and diseases encountered in their vegetable crops including whitefly, spodopteran, aphids, leaf miner, melon decline, powdery mildew, downy mildew, damping-off, early and late blights. Thirteen different active ingredients were selected by FA and nFA respondents to control whitefly (Table 4.2) among which thiocyclam hydrogen oxalate (73%) was the most frequently selected and used by FA respondents followed by acetamiprid (70%), the latter being the most frequently used by nFA respondents (86%). For controlling spodopteran, emamectin benzoate was the most frequently selected insecticide by FA (30%) and nFA (72%) followed by deltamethrin (23% and 20%) respectively. Out of 7 pesticides, abamectin was more frequently selected by FA (8%) and nFA (19%) to control leaf miners while acetamiprid was mostly selected to control aphids by FA (5%) and nFA (3%). Spinosad insecticide was more frequently used by FA respondents (40%) to control thrips. The same products were also selected by nFA respondents to control thrips but with small proportion (3%). Melon decline disease was mainly controlled by FA (10%) and nFA (5%) respondents using a mixture of azoxystrobin and metalaxyl. A combination of Famoxadone and cymoxanil insecticide was the most frequently selected by FA (50%) and nFA (7%) respondents to control early blights attacking tomato and eggplant crops. Late blight disease was controlled more frequently by FA (23%) and nFA (3%) using a mixture of two active ingredients (Benalaxyl and copper oxychloride).

Table 4.2 Frequency and percentage of the appropriate pesticides selected by FA (n=40) and nFA (n=117) respondents to control the common eleven pests and diseases attacking their vegetable crops. A complete table of all active ingredients mentioned is in Appendix 16.

Pest/disease	A.I.	All farms		FA		nFA	
		N	%	N	%	N	%
Whitefly	Acetamiprid	129	82.5	28	70	101	86.3
	Thiocyclam hydrogen oxalate	33	43.5	29	72.5	4	3.4
	Deltamethrin	31	78.1	8	20	23	19.7
Spodopteran	Emamectin benzoate	96	94.3	12	30	84	71.8
	Deltamethrin	32	75.8	9	22.5	23	19.7
	Chlorantraniliprole	14	55.8	8	20	6	5.1
Leaf miner	Abamectin	25	95.1	3	7.5	22	18.8
	Cyromazine	3	7.5	3	7.5	0	0
	Thiocyclam hydrogen oxalate	6	5.1	0	0	6	5.1
Aphid	Acetamiprid	6	71.4	2	5	4	3.4
Thrips	Spinosad	19	44.6	16	40	3	2.6
Melon decline	Azoxystrobin, Metalaxyl	10	66.2	4	10	6	5.1
Powdery mildew	Trifloxystrobin	1	2.5	1	2.5	0	0
Downey mildew	Thiophenate methyl	3	7.5	3	7.5	0	0
Early blight	Famoxadone, Cymoxanil	28	49.3	20	50	8	6.8
Late blight	Benalaxyl, Copper oxychloride	12	47.8	9	22.5	3	2.6

4.4.2.3 Sources of advice on pesticide selection

The survey revealed that retailers were the main source of advice on pesticide selection for both FA and nFA respondents (Figure 4.9). Around 73% of FA respondents depended on retailers in the selection of pesticides in comparison to 82% of nFA respondents. Only 8% of FA respondents sought for pesticide selection guide from the MAFWR in comparison to 10% of nFA respondents. Other sources such as the internet, the FA and local farm practices showed little importance of 8% and less. Nevertheless, there was no significant effect of the source of advice on the respondents' ability to select the proper pesticides.

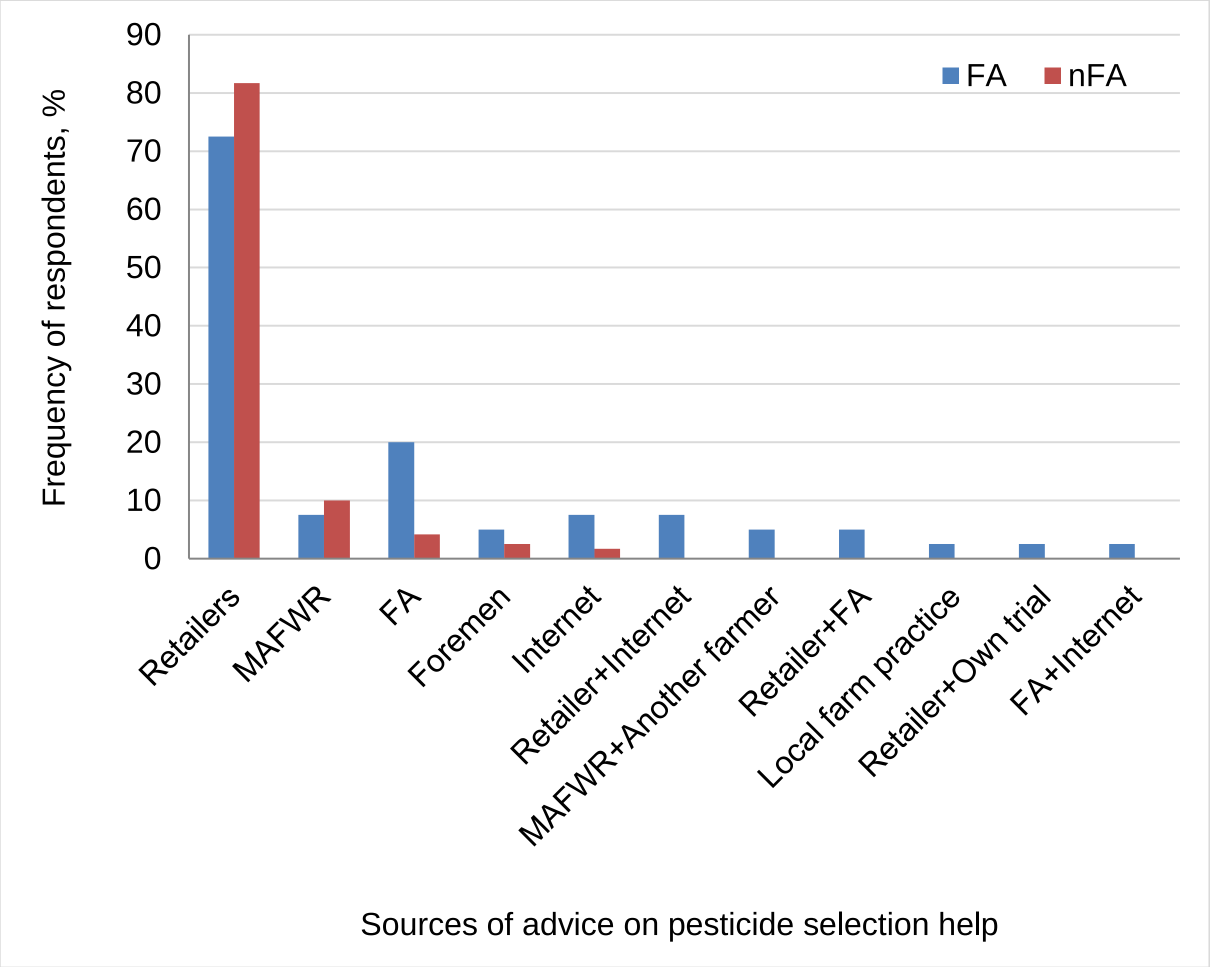


Figure 4.9 Sources of advice on pesticide selection used by FA (n=40) and nFA (n=120) respondents. Respondents could indicate more than one source.

4.4.3 Application of pesticides

4.4.3.1 How FA and nFA respondents decided on the number of pesticide treatments?

Most of FA (90%) and nFA (76%) respondents depended on their own trials to decide the frequency of pesticide spraying during the growing season (Figure 4.10). Around 18% of the nFA respondents followed the local farmers' practices to decide the number of pesticide treatments. No nFA and only 5% of FA followed the pesticide labels. Interestingly, while most sought the retailer's advice on pesticide selection, only 3% obtained guidance on application.

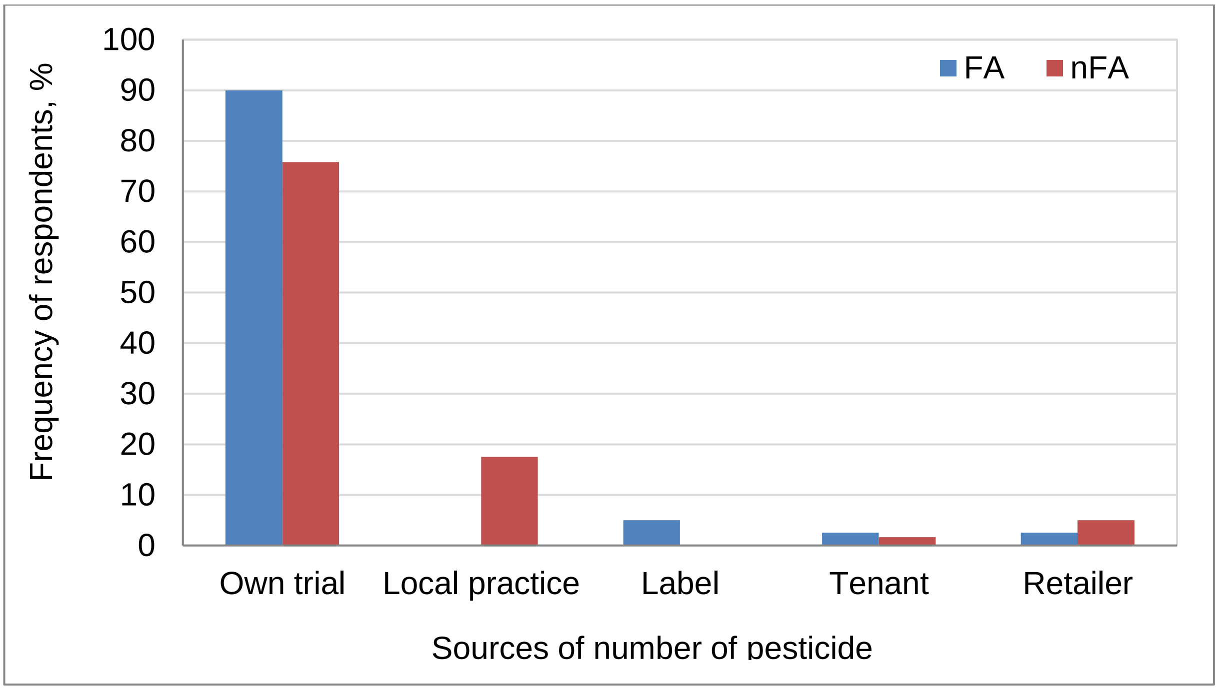


Figure 4.10 Sources of advice on the number of pesticide application treatments to be applied by FA (n=40) and nFA (n=120) respondents.

4.4.3.2 Application of the proper pesticide dose rate.

In this section (4.4.3.2), dose rate refers to the amount of pesticide added to the mixing tank and diluted with water. In other words, it is the concentration of active ingredient in the sprayed pesticide solution, which must be distinguished from the application rate (i.e. the amount of pesticide solution sprayed per unit area).

4.4.3.2.1 Who specifies the dose rate?

Dose rates were specified mainly by FA owners (43%) followed by tenants (30%) and retailers (20%). Foremen of nFA respondents represented the greater proportion (32%) of respondents deciding the amount of pesticides to be used followed by tenants (28%) and owners (26%) (Figure 4.11).

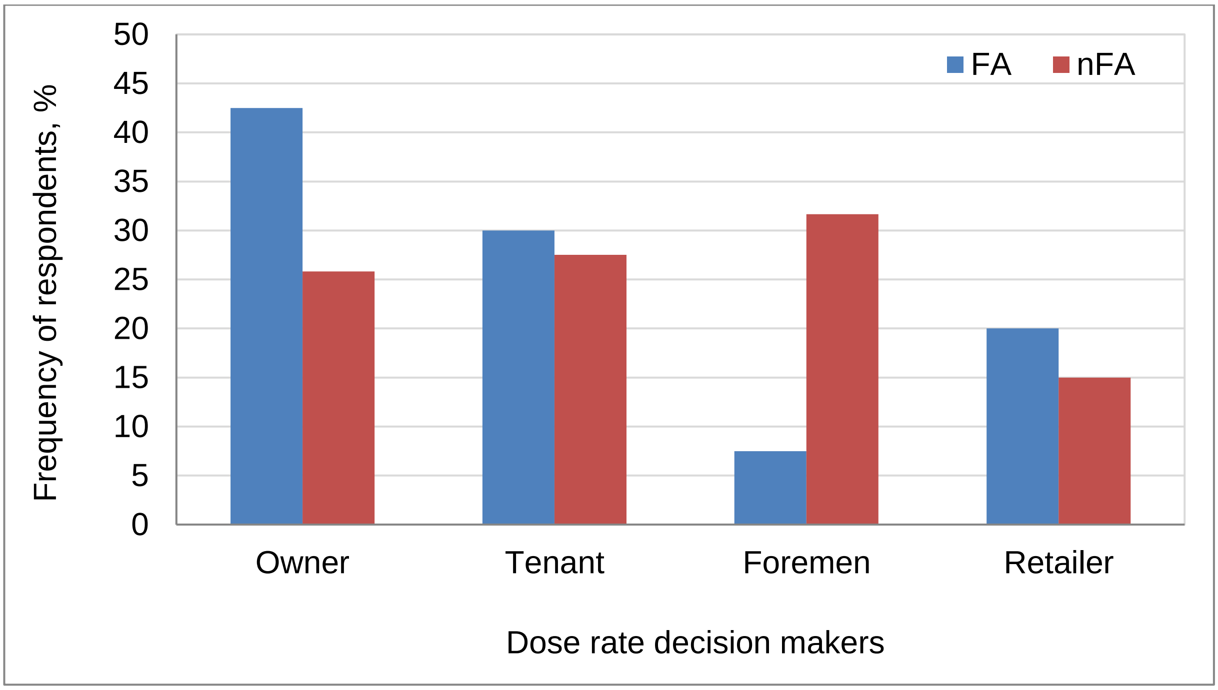


Figure 4.11 Percentage of the dose rate decision makers for both FA (n=40) and nFA (n=117) respondents.

4.4.3.2.2 How was the dose rate chosen?

Around 55% of FA respondents revealed that owners decided the quantity of pesticides to be used followed by retailers (20%) and labels (15%). Two (5%) of the FA respondents depended on their own trials to determine the dose rate (Figure 4.12). Only one (2.5%) FA respondent obtained dose rate information from MAFWR or the FA. Unlike FA respondents, around 74% of nFA respondents obtained pesticide dose rate information from retailers and 24% of them got it from the farm's owners. Only 2% followed the dose rate from labels and none of them obtained the information from MAFWR, FA members or through their own trials.

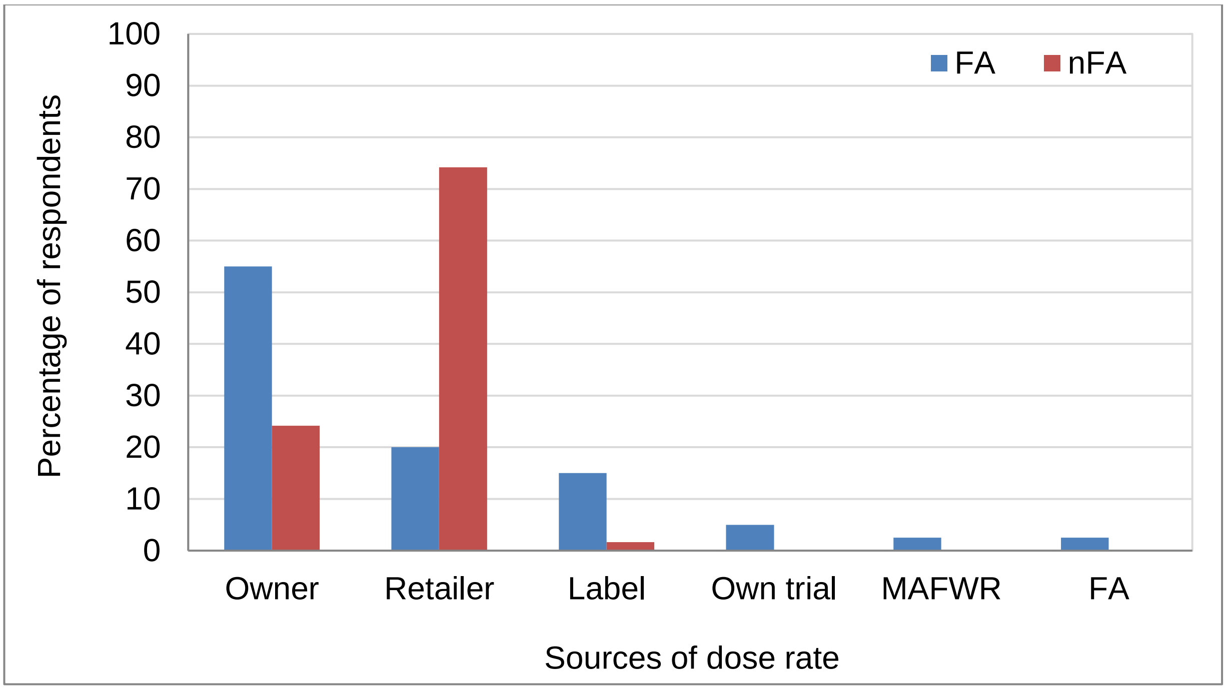


Figure 4.12 Sources of information used to choose pesticide dose rates by FA (n=40) and nFA (n=120) respondents.

4.4.3.2.3 Comparison between FA and nFA respondents in the recommendation of pesticide dose rates.

The dose rate refers to the amount of active ingredient diluted in water. The correct dose rate is assumed here to be the recommended dose rate on local labels allowing a ±10% margin of error. On this basis, nearly half of the FA respondents (49%) selected correct dose rates of pesticides, which is significantly more than the nFA respondents (29%, P< 0.001, Appendix 17). Around 18% of FA and nFA respondents used less than the label recommended dose rates (Figure 4.13). Moreover, around 53% of nFA respondents suggested dose rates more than the recommended doses in comparison to 33% of FA respondents. Owners (47%), tenants (56%) and foremen (46%) of FA gave more accurate dose rate recommendations than owners (28%), tenants (33%) and foremen (24%) of nFA respondents (Table 4.3, P= 0.004, Appendix 17). All age categories of FA respondents revealed higher ability to recommend the correct dose rate than nFA respondents (Table 4.3, P= 0.049, Appendix 17). For instance, 45% of FA respondents aged 30-39 years old recommended the correct dose rate in comparison to 28% of nFA respondents of the same age category (Table 4.3). Education levels were found to increase FA respondents' ability to recommend the correct dose rate in contrast to nFA respondents. Around 60% of FA respondents acquired level 10-12 education level recommended the correct dose rates in comparison to 36.6% of nFA acquiring the same education level (Table 4.3, P= 0.023, Appendix 17). Similar findings were reported for pesticide experience where the difference in correct dose rate recommendations between FA and nFA respondents varied between 10-32% with predominance to FA respondents (Table 4.3, P= 0.049, Appendix 17). Although trained FA respondents showed better dose rate recommendations (68.8%) than nFA respondents (33.5%), but caution need to be taken in consideration due to low numbers of FA and nFA respondents obtained training (Table 4.3, P= 0.004, Appendix 17). FA respondents located at Al Musanah (48%) and A'Suwaiq (55%) indicated better dose rate recommendations than nFA respondents located in the same areas (30% and 43%) respectively (P= 0.029, Appendix 17). FA respondents with a large farm sizes (> 10ha) were more likely to recommend the correct dose rates than nFA respondents (Table 4.3, P= 0.026, Appendix 17).

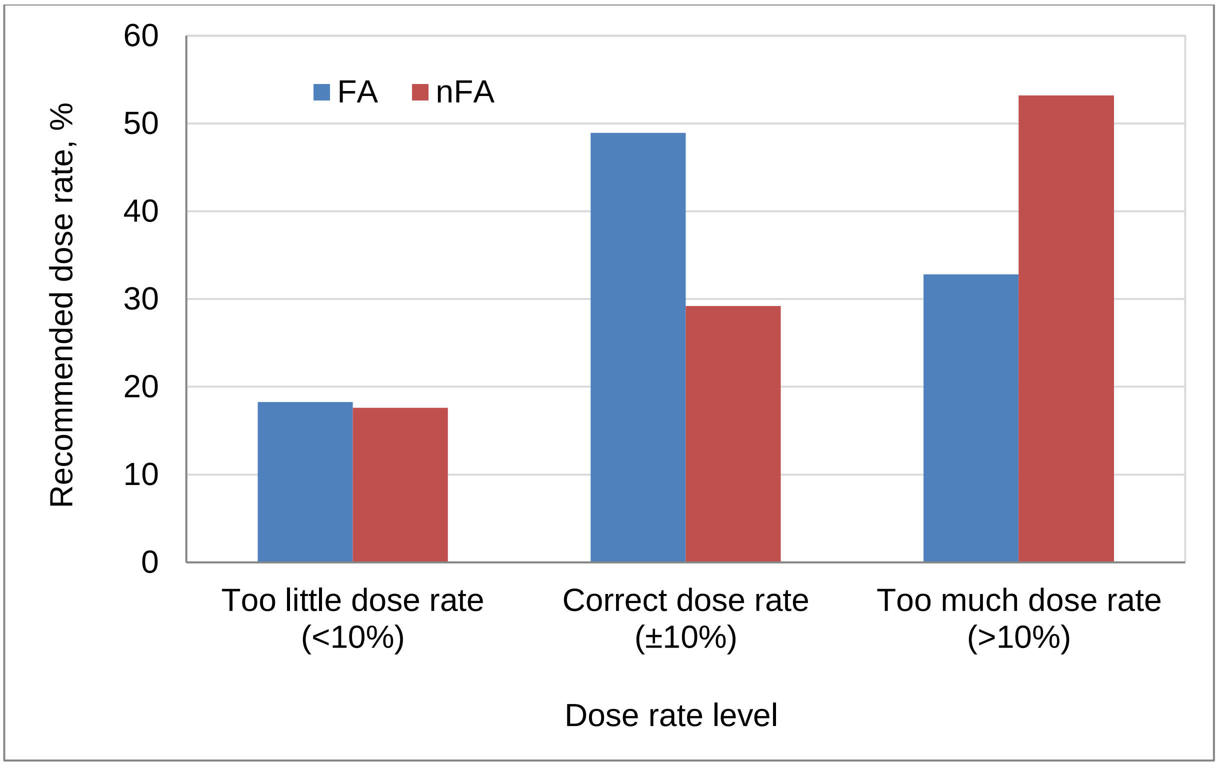


Figure 4.13 Percentages of FA (n=40) and nFA (n=117) respondents recommended different dose rates for the pesticides they selected to control the various pests and diseases attacking their vegetable crops.

Using the data in Table 4.2, the most common vegetable crop (tomato) was selected to investigate the difference dose rates used by FA and nFA respondents of the most pesticide used in both group farms (acetamiprid) to control the most frequent pest (Whitefly). Correct dose rates were considered as within 10% of that stated on the local label. However, most of the FA respondents (68%) used the correct dose rates (±10%) in comparison to 55% of nFA respondents. About 36% of nFA suggested a higher dose rate of acetamiprid compared to 16% of FA respondents. Around 16% of FA respondents in comparison to 9% of nFA suggested dose rates more than 10% lower than the recommended (Figure 4.14).

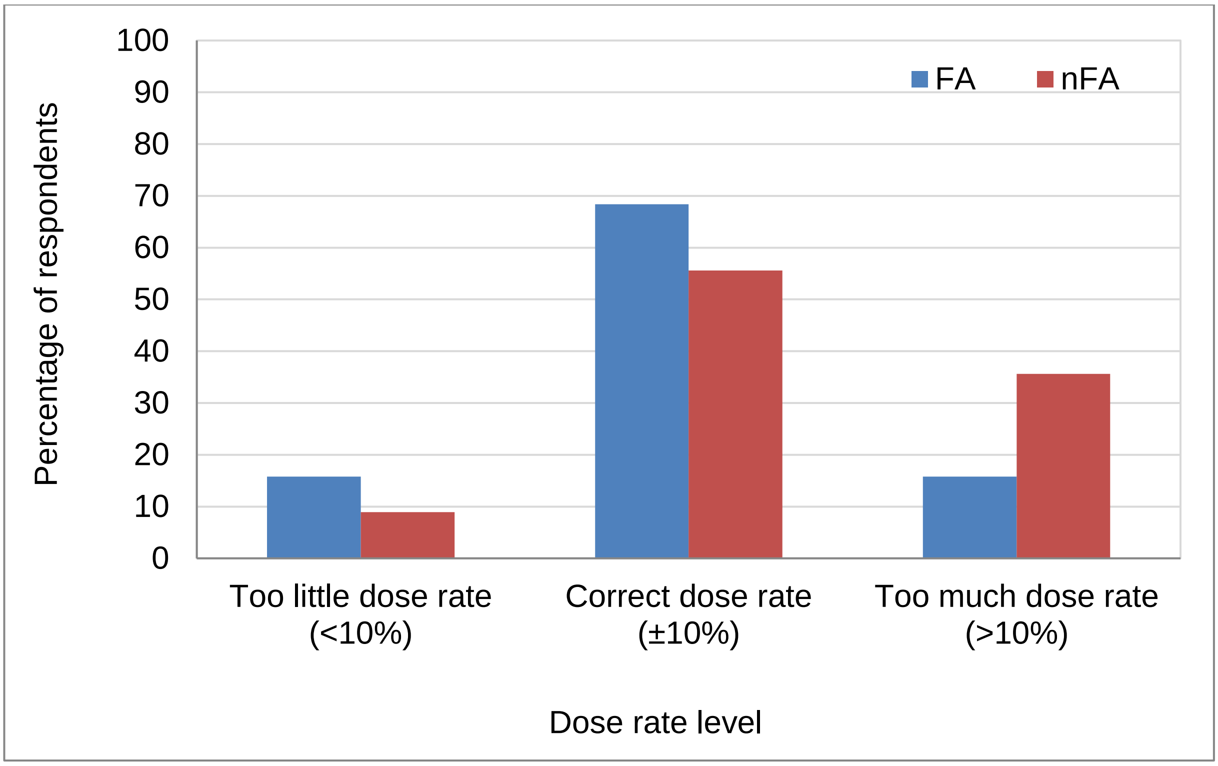


Figure 4.14 Percentage of respondents choosing different acetamiprid pesticide dose rates to control whitefly on tomato crops for FA (n=19) and nFA (n=45) respondents.

Table 4.3 Numbers and average (%) of correct dose rate recommendations of FA (n=40) and nFA (n=117) respondents' based on their status, age, education level, pesticide experience, training and location.*

No.	Variable											P
1	Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker				
	N	16	18	6	21	42	48	6				
	Average, %	47	56	46	28	33	24	49				0.004
2	Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	N	8	11	14	4	3	15	44	27	26	5	
	Average, %	37	45	55	76	55	26	28	30	28	50	0.049
3	Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		
	N	5	14	9	10	21	35	23	28	10		
	Average, %	36. 7	50.1	60.4	45.4	21.6	28.1	29.7	36.6	25		0.023
4	Pesticide Experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49		
	N	15	13	9	3	51	35	19	9	3		
	Average, %	53	41	60	51	27	31	28	31	45		0.049

* Variables with less than three observations were excluded.

Table 4.3: continued

		FA with training	FA without training	nFA with training	nFA without training	P
5	Training	FA with training	FA without training	nFA with training	nFA without training	
	N	5	35	3	114	
	Average, %	68.8	48.2	33.5	28.9	0.004

																P
6	Location	FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	
	N	8	25	14	11	23	4	15	4	14	7	3	3	3	8	
	Average, %	48	55	30	30	43	34	22	13	17	33	33	24	11	27	0.029

													P
7	Farm size, ha	FA 0-4.9	FA 5-9.9	FA 10-14.9	FA 25-29.9	FA 30-34.9	nFA 0-4.9	nFA 5-9.9	nFA 10-14.9	nFA 15-19.9	nFA 20-24.9	nFA 25-29.9	
	N	9	15	5	3	3	47	34	18	6	6	4	
	Average, %	29	54	66	61	59	26	30	22	49	37	35	0.026

4.4.3.2.4 How respondents decided on the PHI period?

The pesticide label served as the main source of PHI information for the FA respondents (75%) and was followed by own trials (18%) and retailers (8%). Local practices were the main source of PHI information for nFA respondents (51%). Pesticide retailers constituted the second source of PHI information for nFA respondents by 23%, followed by the label with 18% (Figure 4.15).

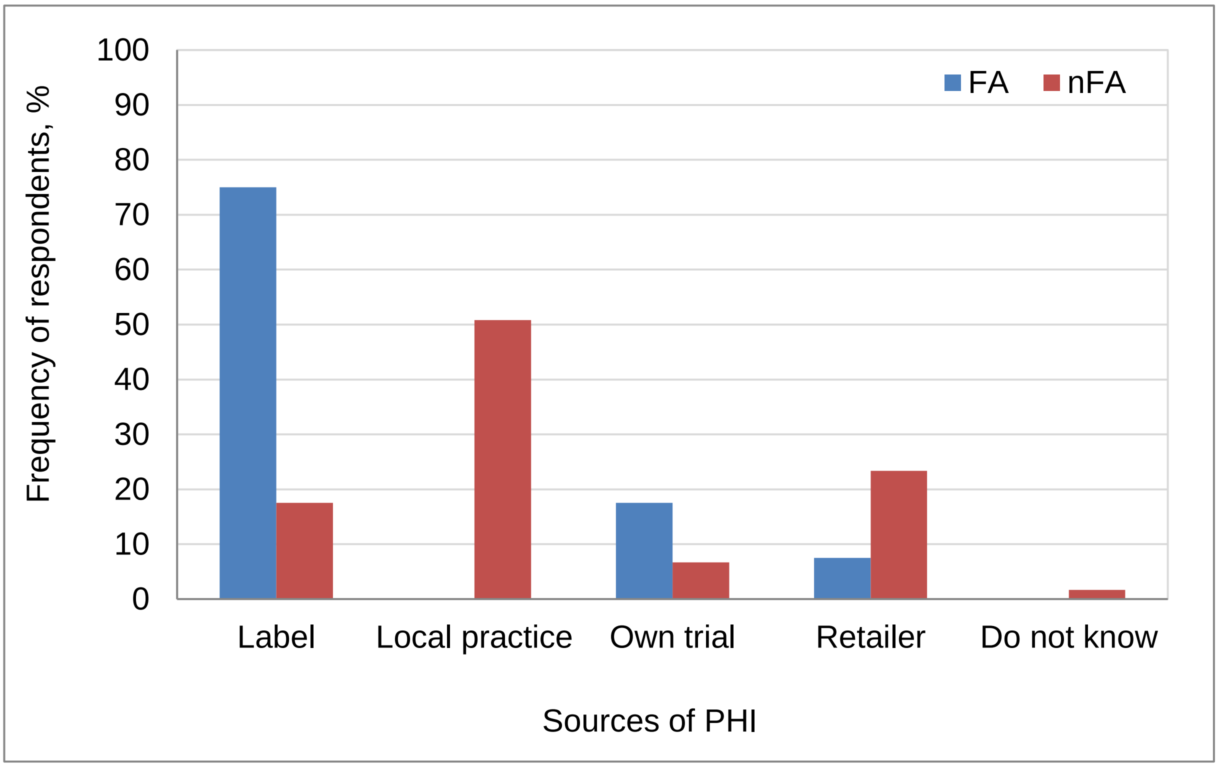


Figure 4.15 Percentages of respondents using different sources of information on PHI period for FA (n=40) and nFA (n=117) respondents.

4.4.3.2.5 Comparison between FA and nFA respondents in PHI recommendation.

Only 48% of FA and 32% of nFA respondents followed the correct PHI recommendations even after choosing a properly selected pesticide. So while FA respondents performed “better” than nFA ($P< 0.001$, Appendix 18), the result is concerning especially because 6% and 28% of the actual PHIs were shorter than the label requirements for FA and nFA respondents, respectively (Figure 4.16). Nevertheless, many FA and nFA respondents revealed levels of PHI longer than that required on the local labels (46% and 40%, respectively). Owner, tenant and foremen of FA indicated better PHI recommendations than owner, tenant and foremen of nFA respectively (Table 4.4, $P= 0.004$, Appendix 18). Age of respondents, education level, years of experience, training and farm size significantly affected the FA respondents’ ability to recommend the correct PHI compared to nFA respondents (Table 4.4, $P< 0.05$, Appendix 18). There was no effect of respondents’ locations on PHI recommendations between FA and nFA (Appendix 18).

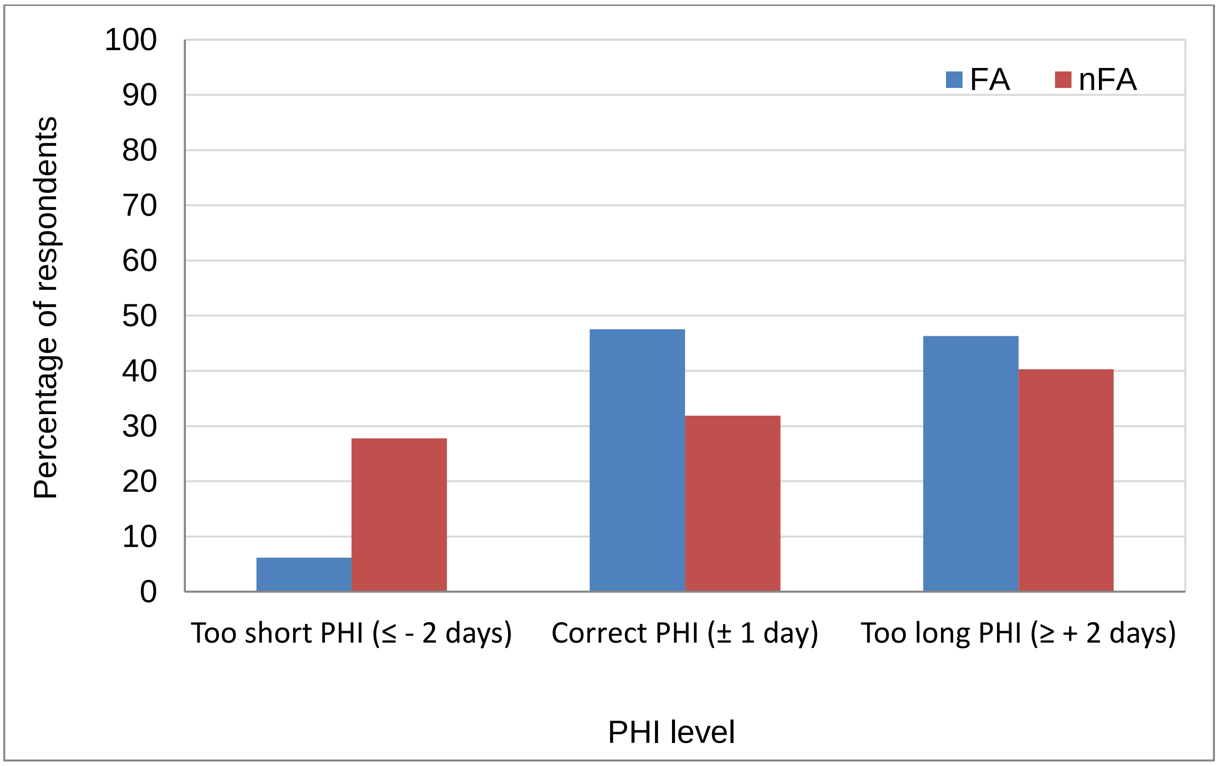


Figure 4.16 Percentage of respondents specifying different PHIs for pesticides selected to control various pests and diseases attacking vegetable crops for recommended FA (n=40) and nFA (n=117) respondents. A "correct" PHI is defined here as that on the pesticide label (±1day).

Using the data in Table 4.2, acetamiprid pesticide was used as an example to assess the PHI recommended by FA and nFA respondents to control whitefly on tomato crops. The PHI was considered "correct" when it was within one day of that stated on the local label. The suggested PHI was considered as longer when the number of days exceeded the correct PHI and considered as shorter when the suggested PHI was less than the correct PHI. More than half of FA respondents (56.3%) suggested the correct PHI in comparison to 26.7% of nFA while 43.8% of FA respondents suggested longer PHI in contrast to 40% of nFA. Moreover, no FA respondents suggested a PHI shorter than the correct one while as many as one third of nFA respondents (33.3%) suggested a PHI less than the correct one (Figure 4.17).

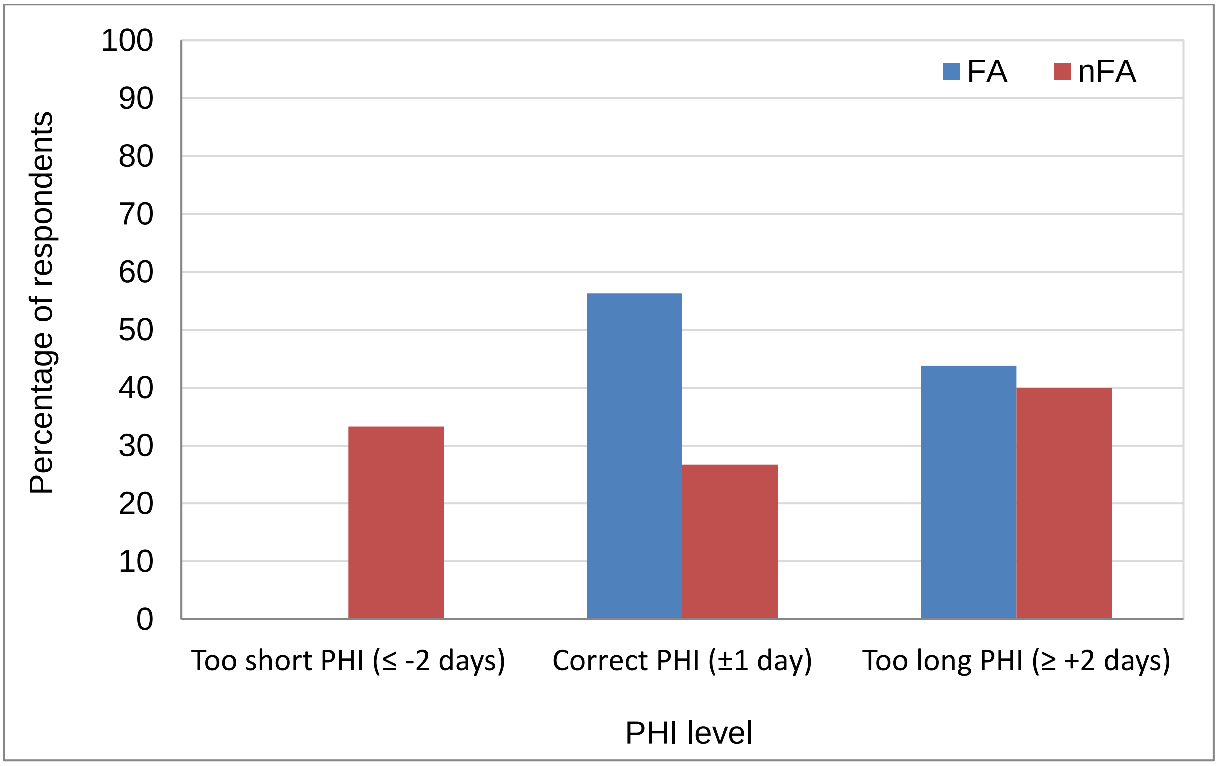


Figure 4.17 Percentages of respondents suggesting different PHIs for acetamiprid pesticide for FA (n=19) and nFA (n=45) respondents.

Table 4.4 Numbers and average (%) of correct PHI recommendations of FA (n=40) and nFA (n=117) respondents' status, age, education level, pesticide experience, training and location.*

No.	Variable											P
1	Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker				0.004
	N	16	18	6	21	42	48	6				
	Average, %	43	38	28	20	19	20	5				
2	Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	0.001
	N	8	11	14	4	3	15	44	27	26	5	
	Average, %	44	22	47	63	11	13	22	14	24	0	
3	Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		0.012
	N	5	14	9	10	21	35	23	28	10		
	Average, %	32	40	41	43	29	17	18	16	10		
4	Pesticide Experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49		0.013
	N	15	13	9	3	51	35	19	9	3		
	Average, %	35	34	50	41	17	17	27	20	10		

*Variables with less than three observations were excluded.

Table 4.4: continued

						P
5	Training	FA with training	FA without training	nFA with training	nFA without training	0.001
	N	5	35	3	114	
	Average, %	45	38	10	19	

																P
6	Location	FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	0.245
	N	8	25	14	11	23	4	15	4	14	7	3	3	3	8	
	Average, %	36	32	12	15	23	5	11	33	37	14	33	32	11	19	

													P
7	Farm size, ha	FA 0-4.9	FA 5-9.9	FA 10-14.9	FA 25-29.9	FA 30-34.9	nFA 0-4.9	nFA 5-9.9	nFA 10-14.9	nFA 15-19.9	nFA 20-24.9	nFA 25-29.9	0.032
	N	9	15	5	3	3	47	34	18	6	6	4	
	Average, %	32	41	26	66	31	14	20	30	15	24	8	

4.4.3.3 Who applies the pesticides?

Most FA (98%) and nFA (95%) respondents revealed that the farm workers or labourers were involved in application of pesticides. Very few FA tenants (3%) were involved in pesticide spraying, while around 4% of nFA respondents indicated that labourers and foremen together were applying the pesticides (Figure 4.18).

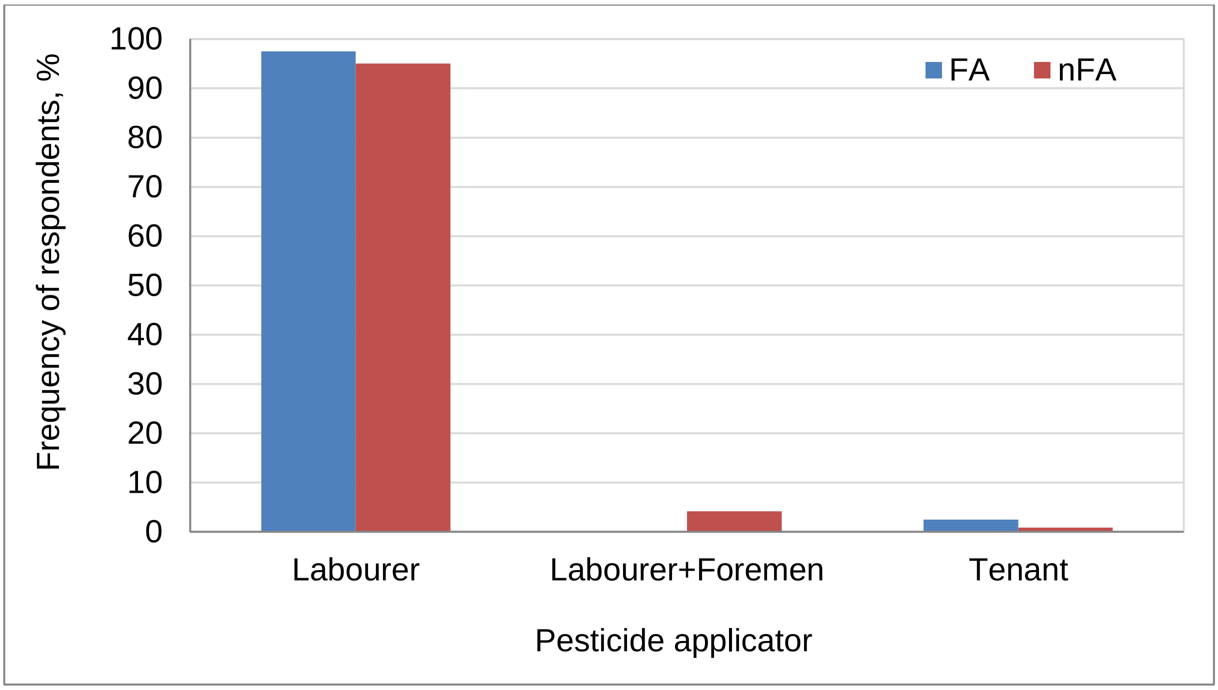


Figure 4.18 Persons on each farm responsible for applying pesticides based on responses from FA (n=40) and nFA (n=120) respondents.

4.4.3.4 Pesticide applicators' training

Application of pesticides requires training of applicators to ensure they perform the work safely for the crop, themselves, consumers and the environment. Nevertheless, around 63% of FA pesticide applicators were not trained and about 99% of nFA applicators also had never participated in any pesticide application training programme. Only 33% of FA respondents indicated that the pesticide applicators at their farms had been trained and this compares with only 1% for nFA respondents' farms.

4.4.3.5 How do respondents normally apply pesticides?

The results showed that 100% of FA and nFA respondents used high pressure machines (3.73 kW) with 3-400 kPa pressure targeting a flow rate of 8-10 L min^{-1} to spray their crops with regardless to the type of crop or the targeted pest or disease.

4.4.3.6 How frequently did respondents check their pesticide spraying machine?

Maintenance of spraying machines is very important to keep their efficiency high. Most of the FA respondents (63%) said that they maintained their sprayer after each spray while 15% reported that they carried out maintenance when required. A further10% maintained their machine prior to the next spray. On the other hand, the majority of nFA respondents only carried out maintenance when required (Figure 4.19) while 14% maintained the sprayers every two months.

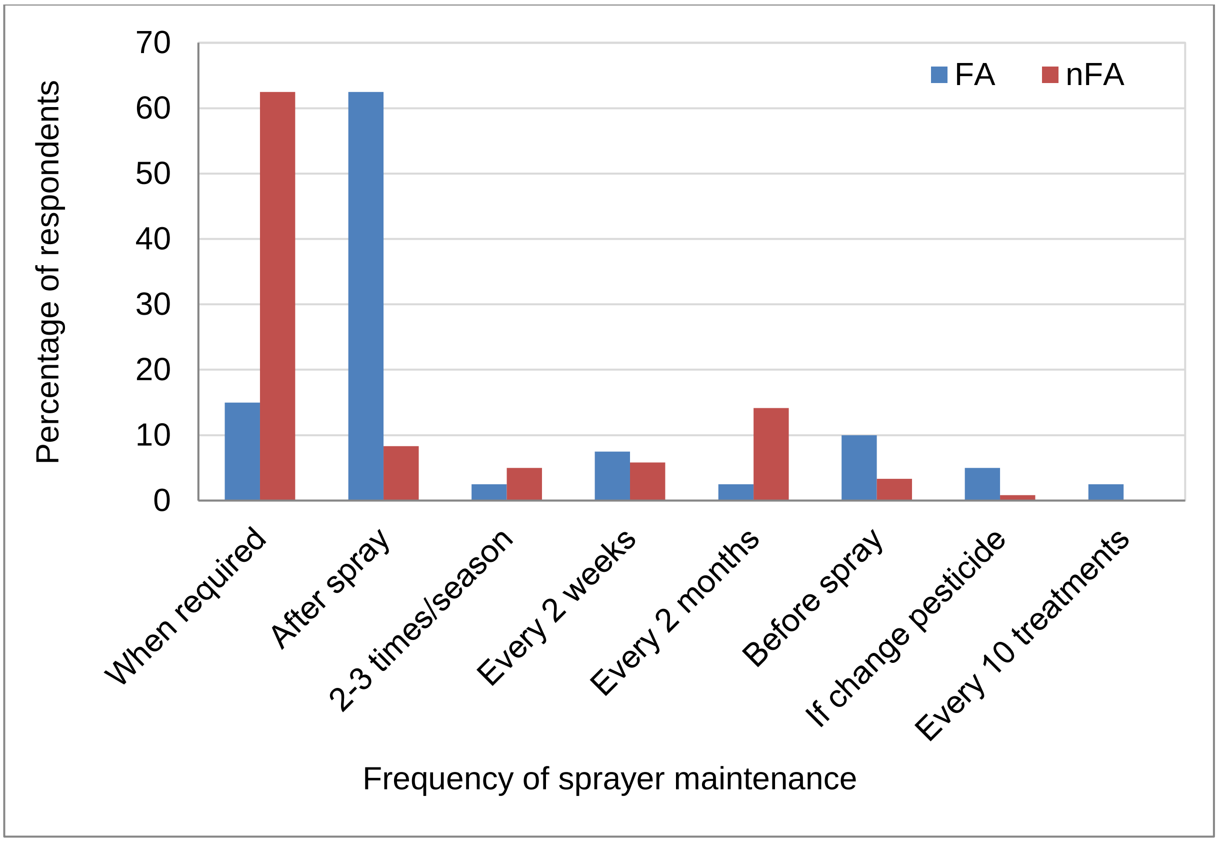


Figure 4.19 Maintenance programme for spraying machines according to FA (n=40) and nFA (n=120) respondents. The question asked was: How frequently do you check the condition of your sprayer?

4.4.4 Focus group discussions

The thirteen FA members who participated in the group discussion revealed that they were mixing pesticides to control the pests and diseases that were attacking their vegetable crops (Appendix 19). They obtained the information about the efficacy of mixing pesticides from different sources such as other farmers, labels or doing some trials in small scale areas. The participants were inclined towards the mixing of more than one pesticide in greenhouses and shade houses to reduce the number of pesticide applications in short periods especially during harvesting stage. Three of the 13 FA members indicated that there were some pesticides that were no longer as effective against the targeted pests and diseases as they used to be. Some farmers increased the concentration of pesticide applied (i.e. decreased the dilution rates) to improve the efficacy of such products but other farmers thought that increasing dilution rates may increase chances of resistance. However, the farmers believed that using the same active ingredient for long periods may lead to the evolution of resistance in the pest or disease to that particular pesticide. They also believed that the generic (me-too) pesticides were less effective than genuine products. Selecting another pesticide was the main approach taken by all focus group members when any of the pesticides were considered no longer effective. For late blight on tomato and wilt and fruit fly on cucurbits, 12, 1 and 5 of the 13 farmers, respectively, disclosed that no protective measures gave successful control. Although resistant cultivars may reduce chemical usage, six farmers indicated that the control achieved by growing such cultivars was less effective than pesticides (Appendix 19). Moreover, eight of the farmers indicated that wilt diseases could not be controlled by pesticides and they could not control it (Appendix 19).

4.4.5 Assessment of recommended application rate and pesticide quality

4.4.5.1 Assessment of application rate (amount of active ingredient/ha)

The assessment of application rate showed that none of the measured average application rates complied with the recommended application rates and most were below the label recommendations. For AL Bedi farm (FA), the mean application rates across the field were below the label recommended rates for both insecticides (emamectin benzoate (- 63%) and deltamethrin (- 30%), blue colour) (Table 4.5). The second FA farm (Al Khadra) also showed low application rates for both insecticides (thiocyclam hydrogen oxalate (- 38%) and emamectin benzoate (- 74%)). Similarly, for A'Salam farm (nFA), the fungicide (metalaxyl + copper oxychloride) was applied at about $^{2}/_{3}$ of the recommended rate (- 68%). Even lower application rates were recorded in Al Qurayhah farm (nFA) where acetamiprid insecticide was only applied at $^{1}/_{17}{}^{th}$ (- 94%) of the recommended rate. In addition, abamectin acaricide and the fungicide (metalaxyl plus copper oxychloride) were also applied at less than half the recommended rates (- 43 and – 13%, respectively). By contrast, in the third nFA farm (Al Maladah), abamectin acaricide was applied at more than twice the recommended rate (+222%, red colour) (Table 4.5).

4.4.5.2 Assessment of pesticide quality

The quality of pesticides is a vital factor that may affect the efficacy of any pesticide to control the target pests and diseases. Out of six pesticides analysed (two from FA farms and four from nFA farms), the emamectin benzoate used in FA farm (Al Bedi) was not complying with the FAO specifications (Table 4.5, pink colour) while the rest of the pesticides all complied with FAO specifications (green colour).

Table 4.5 Assessment of application rate and percentage of active ingredients used in five different plots of five different farms.

Farm location (Wilaya), (FA/nFA)	Name of Pesticide (a.i)/formulation*	Measured concentration (%) of a.i in product ****	Plot area (ha)	Amount of pesticide solution, L			Amount of pesticide In tank (g,ml)	Actual application rate (g,ml/ha)	Recommended application rate (g,ml/ha) ***	% deviation from recomm-ended application rate****
				Amount of pest. solution in tank before spraying (L)	Amount of pesticide solution left in tank after spraying (L)**	amount of pesticide solution used L/plot				
Al-Bedi (Al Musanah), FA	Emamectin benzoate 5% SG[1] +	0.81	0.6 ha	200	9	191	75	119	190	- 63
	Deltamethrin 2.5% EC[2]	2.52					150	239	800	- 30
A'Salam (Barka), nFA	Metalaxyl 15% WP + Copper oxychloride 35%WP, 20% Cu[3]	14.6 + 19.9	0.2 ha	400	88	312	333	1299	1900	- 68
Al-Qurayhah (Barka), nFA	Acetamiprid 20% SP[4] +	19.5	0.5 ha	800	175	625	120	188	200	- 94
	Metalaxy 2.5% WP + Copper oxychloride 40 WP[5]	2.26 39.5					250	391	3000	- 13
	Abamectin 1.8% EC[6]	1.64					125	195	450	- 43
Al-Khadra (A'Suwaiq), FA	Thiocyclam hydrogen oxalate 50% WP[7]	NA	0.7 ha	200	3	197	200	281	750	- 38
	Emamectin benzoate 5% SG	NA					100	141	190	- 74
Al-Maladah (Al- Musanah), nFA	Abamectin 1.8% EC	NA	0.2 ha	200	0	200	200	1000	450	+ 222

* EC: Emulsifiable concentrate   SG: Water soluble granules   WP: Wettable powder   SP: Soluble powder   EW: Emulsion in water.

** The amount of pesticides left in tank measured through spraying graduated tank directly (Al-Salam, Al-Qurayhah and Al-Maladah) whereas the rest with small quantities were measured using measuring jar (Al-Bedi and Al-Khadra).

*** References of recommended application rates (1: https://www.syngenta.com.eg/product/crop-protection/insecticide/proclaim-5-sg, 2: www.saudi-arabia.cropscience.bayer.com, 3: Local label, 4: http://www.arystalifescience.co.ke/product_categories/insecticides/?product_id=1731, 5: https://www.nexles.com/eu/syngenta-fungicide-ridomil-gold-plus-42-5-wp-30-g.html, 6: https://www.syngenta.com.au/product/crop-protection/vertimec and 7: http://www.arystalifescience.co.ke/product_categories/insecticides/?product_id=1719).

**** Pink: not compliant with FAO specifications. Green: complies with FAO specifications. Red: above recommended application rate. Blue: below recommended application rate.

4.4.6 Assessment of spatial variability of pesticide application

The amount of pesticide deposited per unit area was quantified in three fields (Al Bedi, A'Salam and Al Qurayhah) to measure the uniformity of the chemical deposition. The data summary of the three fields was concluded in Table 4.6 including standard deviation, coefficient of variation ratio and the skewness. The overall data revealed the lowest standard deviation (SD), CV ration and skewness in Al Bedi field followed by Al Qurayhah and then A'Salam.

Table 4.6 Summary statistics of amounts of pesticide applied in three fields. All amounts are in ml of solution collected in sampling bottles. Box plots are provided in Appendices 3.7, 3.9 and 3.11.

Field	Pesticide	Samples	Mean, ml	Median, ml	Minimum ml	Maximum ml	Standard deviation ml	CV, %	Skew-ness
Al Bedi (FA)	Emamectin benzoate and deltamethrin	98	2.59	2.57	1.04	4.40	0.819	31.6	0.027
A'Salam (nFA)	Metalaxyl	89	4.44	4.43	0.41	8.60	1.63	36.8	0.290
Al-Qurayhah (nFA)	Acetamiprid, (Metalaxyl + Copper oxychloride) and Abamectin	100	3.22	3.18	0.27	6.26	1.24	38.7	0.193

CV: coefficient of variation.

The geostatistical analysis indicated that A'Salam field was the most variable in terms of pesticide application (the nugget plus the sill variances in Table 4.7) and Al bedi was the least. Nevertheless, approximately two-thirds of the variation in Al Bedi field was spatially-correlated variation (35%, Table 4.7, Figure 4.20 A) compared to about half in A'Salam (51%, Table 4.7, Figure 4.20 B) and less than 10% in Al Qurayhah (91%, Table 4.7, Figure 4.20 C). The very short-range values for both Al Bedi and A'Salam fields indicate that the spatially-correlated variability occurred over very short distances (10.6 m and 6.1 m, respectively, Table 4.7, Figure 4.20 A, B), implying very uneven pesticide application. It is emphasised that the much smaller sill variance and the consequently small extent of the spatially-correlated variation in Al Qurayhah field does not imply that pesticide application was more even. The high nugget variance makes it clear that this is not true and most of the variability is random and spatially-independent (Table 4.7, Figure 4.20 C).

Table 4.7 Geostatistical parameters of the variogram model for the spatial variation in the amounts of pesticides deposited (in millilitres) in Al Bedi field (n=98), A'Salam field (n=89) and Al Qurayhah field (n=100). Least squares analyses are included in Appendices 3.8, 2.10 and 3.12.

Field	Model	Nugget variance	Range, m	* Sill variance	** Spatially-correlated variation, %
Al Bedi	Spherical	0.224	10.6	0.415	35%
A'Salam	Spherical	1.45	6.11	1.40	51%
Al Qurayhah	Cubic	1.46	55	0.148	91%

* Sill variance is the fitted semi-variance at the range minus the nugget semi-variance.
** Spatially-correlated variation = 100 (nugget)/(nugget + sill). NB. The higher the percentage, the smaller the amount of variation that is spatially-correlated.

The extent of variability in pesticide application in all three fields can helpfully be visualised in two ways. First, by the frequency distributions (Figure 4.21 A-C) illustrating the extent to which pesticide applications deviated from the calculated target amount (Figure 4.21 A-C). It should be noted that these amounts are the farmers' targets and not the label recommendations, from which these targets deviated considerably. Secondly, given the existence of spatially-correlated variation, mapping the actual pesticide application across each of the fields shows distinct patches in each field where pesticide application was lower or higher than the farmer's target (Figure 4.22 A-C).

In Al Bedi field (FA, Al Musanah) the variability in amounts of emamectin benzoate and deltamethrin deposited on the tomato plants ranged from 1ml up to 4.4ml with 56% of measurements lower and 41% higher than the target application rate of 2.8 ml (Figure 4.21 A). This high heterogeneity in the application process is reflected in the spatial variation in the distribution of insecticide mixture. There was a tendency for applications in the south east and extreme north-west of the field to be above target with the majority of the remainder of the field receiving less than target (Figure 4.22 A).

Applications of the fungicide (Metalaxyl + Copper oxychloride) to the tomato crop in A'Salam field varied more widely ranging from 0.41ml to 8.6ml compared to the targeted rate of 4.9ml (Figure 4.21 B). As in Al Bedi field, a majority of observations (61%) were below the target with 36% above target. Applications in the centre of the field and in the south-eastern corner were particularly low while patches with above target applications were frequent in the north east and south of the field (Figure 4.21 B).

In Al Qurayhah field (nFA, Barka), the spatial variation about the 3 ml target was distributed more randomly ranging from 0.27 ml to 6.26 ml but with over 90% of the variation showing no spatial correlation and a very high nugget variance relative to the sill (Table 4.7). Such variation as did occur, was evident over long distances in the field (the range was 55 m, Table 4.7). More observations (54%) showed above target applications with 44% below target. Below target applications (blue) tended to be located along an east to west transect through the middle of the field and especially in the east and south-west of the field. Above target applications (brown and red) particularly occurred along the northern and to a lesser extent on the southern field margins (Figure 4.22 C).

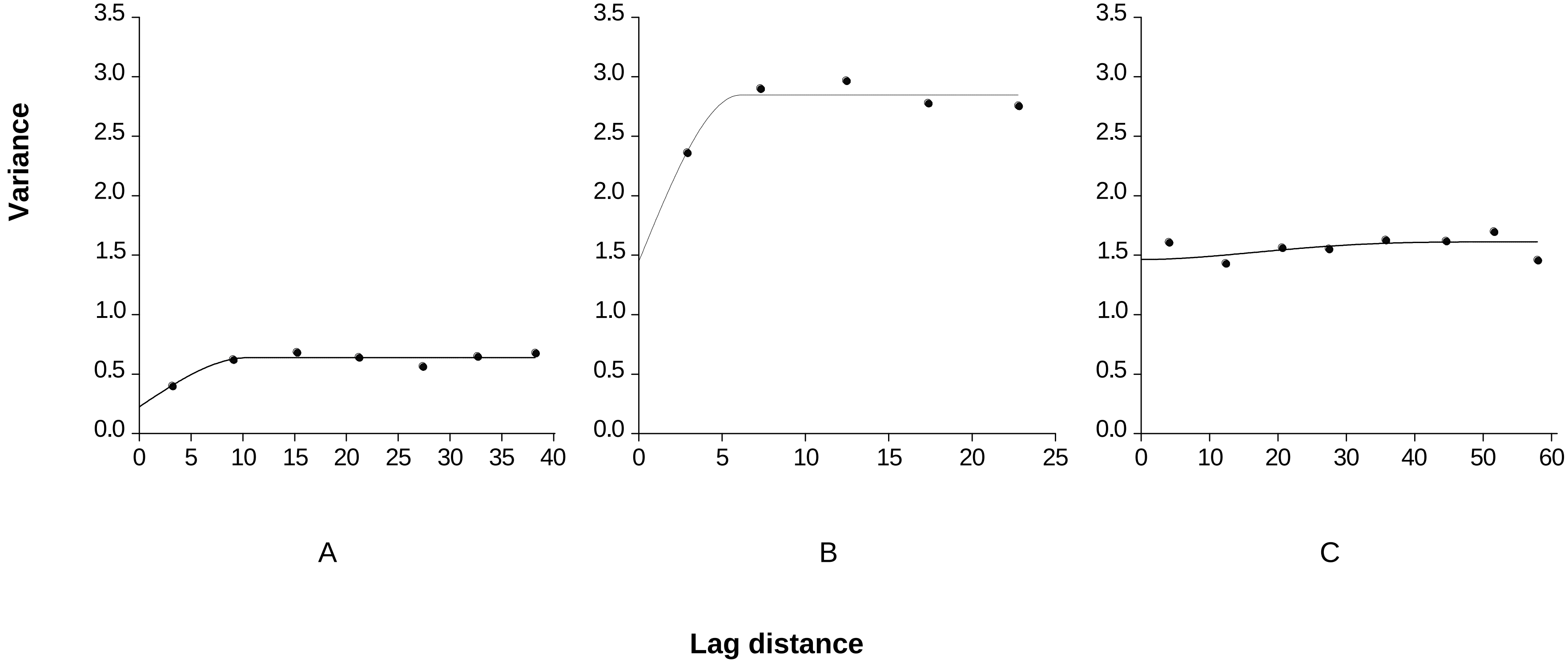


Figure 4.20 Variograms for the amounts of pesticide deposited in 20cm funnels in (A) Al Bedi, (B) A'Salam and (C) Al Qurayhah fields. Geostatistical parameters of the fitted spherical models are in Table 3.7. Least squares analysis of the fitted variogram models are in Appendices 21, 23 and 25.

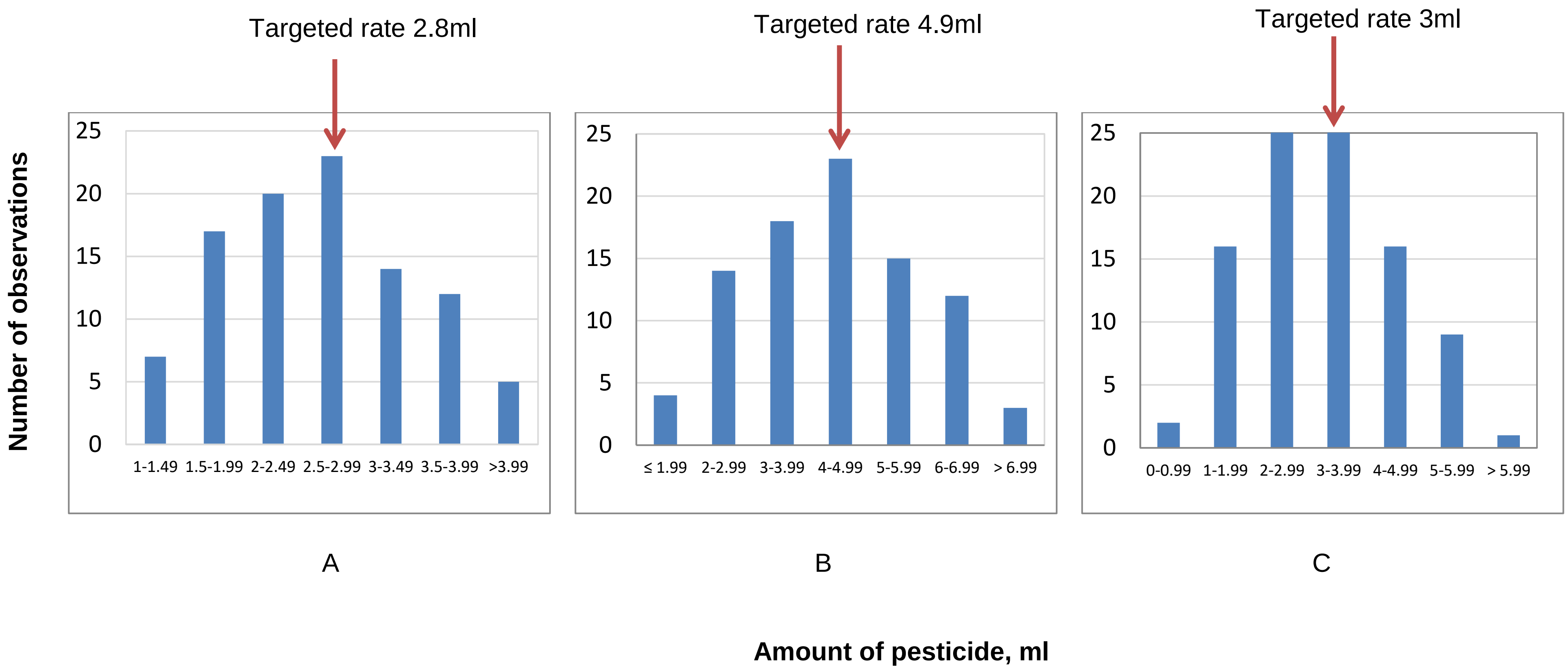


Figure 4.21 Frequency distribution of pesticide' mixtures applied to tomato crops and deposited in 20cm funnels in (A) Al Bedi, (B) A'Salam and (C) Al Qurayhah fields. At the dilution rates of the spray tank, the downward pointing arrows indicate the targeted amount of spray that should have been deposited on a 20cm diameter circle, i.e. for field (A) 2.8 ml, (B) 4.9 ml and (C) 3.0 ml for each field.

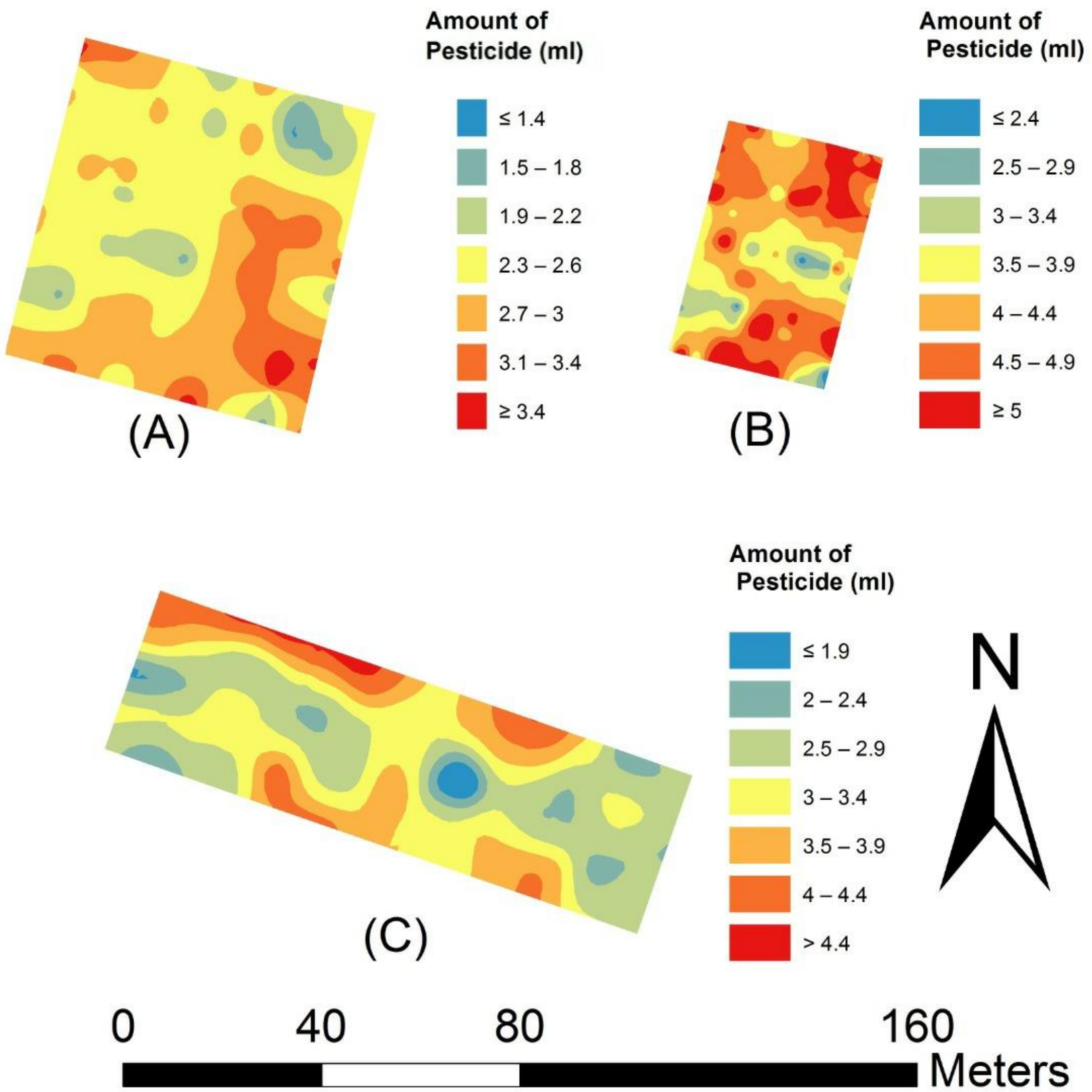


Figure 4.22 Kriged maps showing the spatial variability of the amount of pesticides mixture applied to tomato crops based on measurements of amounts deposited in 20cm funnels in (A) Al Bedi, (B) A'Salam and (C) Al Qurayhah fields. At the dilution rates of the spray tank, the targeted amounts of spray that should have been deposited on a 20cm diameter circle, were (A) 2.8 ml, (B) 4.9 ml and (C) 3.0 ml for each field.

4.5 Discussion and conclusion

4.5.1 Discussion

The main objectives of this Chapter are to compare the ability of Farmers' Association (FA) and non-farmers' association (nFA) respondents to select proper pesticides and to discuss if there are any differences between the two groups in proper pesticide applications to control various pests and diseases attacking their vegetable crops. Whitefly, thrips and downy mildew were the most frequently reported problems in FA and nFA respondents' farms. There was no difference between FA and nFA respondents for the same pest or disease revealing similarity in types and extent of problems. Since most of the farmers grew tomato and eggplant in the same area, it is not surprising that the same problems were associated with these crops. Moreover, tomato crops were severely infected by early blight disease (causal organism: *Alternaria solani*) and late blight disease (causal organism: *Phytophthora infestans*) during the survey period. This may account for the frequent occurrence of these diseases in FA and nFA farms.

Although FA respondents performed better than nFA respondents in the selection of proper pesticides for most of the eleven pests and diseases, yet there was no significant difference between FA and nFA respondents. However, the majority of both groups' respondents obtained the advice for pesticide selections from the same source (retailers) which seems they trust more. The results may provide a clear picture of the role of governmental extension services, as a source of advice, and the private pesticide retailers. Were the extension service technically stronger and more visible, more farmers might seek advice from them and less from private sellers and vice versa. However, the lack of knowledge due to low educational levels, almost non-existent official training programs and weak extension services meant the famers had to depend on pesticide sellers for pesticide selection. Similar findings were reported in Greece and Bangladesh by (Damalas et al., 2006 and Akter et al., 2018). Pesticide sellers are employed by for-profit companies or shops, whose objective is naturally to sell pesticides and remain profitable so their advice and pricing may relate to pesticides they have in stock and they may be unaware of possible non-chemical options. They also understand that most farmers prefer to buy pesticides that cause instant killing (knock-down) of the target pests and diseases (Cameron, 2007, Ngowi et al., 2007, Hashemi and Damalas, 2011, Schreinemachers et al., 2017, Mengistie et al., 2017). If farmers do not observe a quick killing action of a pesticide, it might be replaced with another pesticide (Sharifzadeh et al., 2018).

Many factors may affect the decision making for pesticide selection such as; education level, training, experience, farm size, price of the pesticides and the crops they produce (Adejumo et al., 2014 and Halimatunsadiah et al., 2016). In this study there was no significant difference between FA and nFA status, age, education level, pesticide experience, training, location and farms size on respondents' decision. Pesticide cost is another problem affecting the decision making of farmers for selecting pesticides although it was not considered as a factor in the current study. In Bangladesh and Pakistan, it was reported that farmers encountered pesticide cost problems in selecting pesticides during the season because of price fluctuation (Sabur and Molla, 2000 and Mubushar et al., 2019). Due to lack of capital, vegetable growers tend to choose older and broad-spectrum active ingredients because of their lower price and availability in the market. The same was also reported in Ethiopia amongst vegetable growers (Mengistie et al., 2017).

However, the relationship between correct pest and disease diagnosis and proper selection of pesticides showed a positive relationship. This may be helped by better knowledge diffusion between FA respondents which could improve the knowledge of diagnosis and proper pesticide selection amongst association members which was also reported by Al Zadjali et al. (2014) in Oman.

The wide range of active ingredients used by FA and nFA respondents indicated the availability of many products in the market and advertisements or incentives given to farmers such as credit purchase or special sale offers may have encouraged the farmers to buy more and different products to control the pests and diseases infesting their crops. For instance, thirteen different active ingredients were selected to control whitefly, ten different actives to control spodopteran and eleven to control early blight. Nevertheless, FA respondents tended to select and use branded or patented pesticides that are more effective and not found in Oman local market as generic products such as thiocyclam hydrogen oxalate to control whitefly, chlorantraniliprole to control spodopteran and spinosad to control thrips. Branded/patented pesticides are more expensive than generic ones which explain why nFA respondents tended to use cheaper, outdated and non-patented pesticides such as acetamiprid to control whitefly or carbendazim to control blight diseases. Another reason for these preferences may be that FA respondents export most of their products outside the country and they may get better or higher prices for their produce in comparison to nFA respondents who tend to sell their produce in local markets where prices are lower and so they will wish to reduce their input costs by buying lower price pesticides.

Owners of FA farms were found to be more involved in deciding the amounts of pesticides to be used whereas the foremen were more involved within nFA farms. This finding was not surprising since most of the nFA farms are rented to second or third parties through letting and sub-letting processes. Dose rate (dilution rate) was frequently chosen by the owner for FA farms while it was frequently based on advice from the retailers for nFA respondents. Dependence of nFA respondents on retailers' advice could be due to low level of education, little experience, lack of training, an exchange of information between farmers in same area and the weakness of extension services.

FA respondents more frequently used the recommended pesticide dose rates stated on the labels in comparison to nFA respondents who were more likely to exceed the recommended doses revealing that significant percentages of pesticides were being over dosed. Similar findings have been reported in many studies worldwide (Sabur and Molla, 2000, Damalas, Theodorou and Georgiou, 2006, Abhilash and Singh, 2009, Jha and Regmi, 2009, Atreya et al., 2011, Khan and Damalas, 2015, Sharma, 2015, Zhang et al., 2015 and Sun et al., 2019). However, even with the most common insecticides (acetamiprid) used by FA and nFA respondents to control the most common pest (whitefly), 36% of nFA respondents were found to exceed the dose rate by more than 10% compared to 16% of FA respondents.

The correct recommendation of dose rate was associated with respondents' status, age, experience, education, training and farm size. However, it is important and worth exploring the reasons for over-dosing pesticides by farmers. Increased pesticide misuse could be associated with visits by pesticide retailers and company representatives who were (informally) observed scouting in survey areas in order to advertise their products. Furthermore, pesticide sellers gave different types of incentives such as credit payment and unlimited quantities to make it easier for pesticide users to spray more chemicals, a similar finding being made in Cambodia, Laos, Vietnam and Nepal by Schreinemachers et al., (2017) and Rijal et al., (2018) who suggested that the probable shortage of expert advice and technical support on pesticides for farmers who may patronize these shops was leading to problems of indiscriminate use, high frequencies of pesticide applications with the same mode of action which may lead to pest resistance development, pest resurgence and associated indirect costs of pest control (Onwona Kwakye et al., 2019). It was reported in Pakistan that around 99% of respondents encountered pesticide effectiveness problems when used to control various pests and diseases (Mubushar et al., 2019). In addition, the price of the produce was found to be determining factor that was driving farmers to use more or less pesticides during the season in Bangladesh and Iran (Rahman, 2016 and Abadi, 2018). Unlike FA respondents, nFA respondents did not depend on labels for dose rate information because most of them could not read Arabic so they trusted local practices, neighbours and retailers for advice. The same problem was also confirmed by Saleh Abbassy (2017) in Egypt who found that only 2-3% of growers read pesticide labels or instructions stated on the containers when using pesticides.

FA respondents showed better adherence to the label PHI while many nFA respondents did not adhere to the PHI period stated on the labels with the risk of increased pesticide residues in their produce. Since there is no control over PHIs and since residues are seldom monitored in local markets in Oman, farmers will naturally seek to maximise their profit and, to put the most favourable interpretation on their practices, they may be unaware of the potential consequences of their actions on consumers' health and welfare. Indeed, during the survey, some of the farmers expressed the view that using pesticides just before harvest could improve crop quality and its visual appearance which attracts the customers. A similar view was also expressed amongst vegetable growers in Nepal (Shrestha et al., 2010) and Armenia (Tedevosyan et. al., 2013). Clearly, farmers' practices and attitudes reflect their education, experience and training (Akter et al., 2018). Non-compliance with

PHI interval stated on the pesticide labels was also found to be common amongst vegetable growers in Vietnam (Tan, 2021). In Oman, this study indicated that farmers with lower education levels need training on proper farming practices or IPM including pesticide applications. Participation of all farmers and pesticide retailers in the country is needed to mitigate the adverse consequences on people and the environment of pesticide misuse and to improve product quality and safety. The inclusion of retailers is important since they are major sources of information and should be able to give proper advice on pests and diseases, dose rates and PHI for each particular pesticide, a similar point being made by Halimatunsadiah et al. (2016) in Malaysia.

In both FA and nFA farms, labourers were applying pesticides. For around 70% and 99% of the FA and nFA respondents respectively, pesticide applicators had never had any formal training in pesticides or their application. This not only highlights the scope for potential abuse of pesticides but also the urgent need for training and educating these personnel. Although the owners, tenants and foremen instructed labourers on pesticide spraying, in many cases during the survey, labourers were observed to spray the crops in unstructured ways and without any supervision leading to potential for abuse, human and environmental contamination, and increasing residues in vegetables. There is also the extra cost to farmers due to waste of spray.

All FA and nFA respondents were using stretcher-mounted high-pressure sprayers and cleaned sprayers after spraying or at least when required, but none of the respondents applied regular maintenance to their pesticide spray equipment. Since the efficiency of spraying depends on the type and condition of sprayer (Xiao et al., 2020), these findings revealed a requirement to assess the suitability of machines for all stages of vegetable plants along with pressure, flow rate and nozzle sizes.

The focus group discussion revealed that the use of pesticide mixtures was common amongst FA respondents, which has also been reported as a common practice throughout the world by Halimatunsadiah et al. (2016). Farmers mix pesticides to control several problems at once due to short season time which was also reported by Mengistie et al., (2017). Farmers believed that mixing of pesticides makes them more effective (Konradsen et al., 2003 and Schreinemachers et al, 2017) and cost-effective as well (Sherwood et al., 2005 and Ngowi et al., 2007). During the discussion, FA participants indicated that some pesticides were no longer effective against target pests and diseases as evidenced by a need to decrease the dilution rate or increase the application rate which may elevate the chance of resistance developing. They were also aware that the repeated use of the same active ingredient will encourage the evolution of resistance in pests (Rijal et al., 2017). In addition, the use of me-too products may increase the problem of overuse of pesticides, resistance problems, increase phytotoxicity and higher levels of residues in the produce. There is a distinct problem of over-dependency on the use chemical measures and no involvement from governmental authority or FA to introduce IPM programmes including biological, resistant cultivars and non-chemical measures such as pheromone traps or other measures (Bass et al., 2015 and Lucas et al., 2015). This may be forcing farmers to depend on their own trials based solely on the use of pesticides. Gisi and Leadbeater (2010) suggested that managing resistance is important strategy for effective use of pesticides. The development of resistance leads to the inability of some chemicals to control certain pests and diseases and their resurgence as was suggested by some respondents in this study for late blight in tomato, cucurbit wilt and cucurbit fruit fly.

Assessment of application rates for both FA and nFA farmers indicated that none of them applied the correct application rates. During the survey and assessment of application rates, it was frequently observed that farmers did not calibrate their machines before spraying and none of them checked the validity of their machines or the method of application to get the application rates required. This may reveal the lower and upper application rates used by FA and nFA farmers which were far away from the recommended rates. Many studies have of course demonstrated the importance of using proper calibration methods (Gil et al., 2007), application rate (Sedlar et al., 2013 and Miranda-Fuentes et al., 2015), and spraying technique (Nath et al., 2017) to improve efficiency and efficacy of pesticide application.

Measurements of the concentration of active ingredients showed that one out of six samples did not comply with the FAO specifications indicating the need to expand the quality control survey to cover most, if not all, pesticides used in Oman. Low-quality pesticides lead to many adverse effects to crops, humans and the environment due to their excessive or inappropriate use. Such products may also lead to the evolution of resistance to many active ingredients regardless of whether these products are genuine or duplicated (‘me too’). The best way to ensure the product quality is to apply batch to batch analysis for registered products at the point of entry. According to Durmusoglu et al., (2008) and Pauluhn and Ozaki, (2015), ‘me too’ or generic pesticides were found to be less effective against the targeted pests and diseases in comparison to patent products.

One of the aims of the study was to quantify spatial variability of deposition rates for the farmers’ practice of applying pesticides by ‘spraying’ the plants. The high heterogeneity in the amounts of pesticide deposited in all three fields tested meant a minority of tomato plants were receiving the targeted rate and as few as 1-3% of samples were at the correct dose. The failure to achieve the correct dose is very critical. For instance, applications of too little pesticide could lead either to less efficacy in controlling the targeted pest or disease or encourage development of resistance in the long-term. The higher doses could cause more pesticide residues on the crop as well as polluting the environment. Reasons for the uneven deposition when spraying a crop largely relates to the sprayer type and the spraying method used. Other more systematic errors could relate to incorrect calibration of the spraying machine and of sprayer pressure and the sporadic maintenance of sprayers. Other studies have shown the importance of nozzle type, size and inclination causes an uneven distribution of pesticides in the fields and the use of the same nozzle type and size for different pesticide formulations may increase pesticide spray drifts and non-uniform distribution (Ferguson et al. (2015)**.** Wind, walking calibration, farming practices could also be counted as factors affecting spray deposition uniformity. In India, Nath et al. (2017) demonstrated that more than 95 - 98% of sprayed pesticides increased drifts due to wind and spraying method which was across entire agricultural field. They concluded that changing spraying method by using spraying atomizers instead of normal sprinklers and sprayers has come up to be best solution for better pesticide application efficiency. Nevertheless, in this study, it was observed that farmers ignored the wind direction factor that increase spray drift and cause non-uniform pesticide deposition on targeted plants. The same farmers’ attitude was also reported by Tandi et al., (2014). According to Wise et al.

(2010), a precise combination of sprayer type, water volume and pesticide is needed to provide optimal performance against key insect pests and fungal diseases of vineyards in the eastern United States. Calibration of spraying machines is very important, first to ensure the proper amount of pesticide is applied to an area of land and secondly, to ensure the uniform application of product across the entire length of spray lines or field. An excessive application rate could lead to crop damage and high residue levels of pesticides and a greater risk of environmental pollution. On the other hand, parts of fields receiving sub-optimal doses could lead to ineffective control of the problems and perhaps the additional cost of repeating the spraying process. Proper understanding of calibration plays a vital role in effective spraying and control measure of a certain pest or disease. Inconstant sprayer pressure could be one of the important causes of unevenly pesticide droplets distribution and deposition. According to the field observations in all three farms, not one of the farmers tried to measure the machine pressure during spraying. However, the application pressure and nozzle type have the greatest impact on coverage and droplet number density (Ferguson et al., 2016). The regular maintenance of pesticide spraying machines could improve the performance and help to achieve a more even delivery of pesticides on targeted crop. On the other hand, the local farmers did not appear to be concerned about type of spraying system they were using or whether the sprayer or nozzle type and size, was suited to pesticide application and the crop. According to Nuyttens et al. (2007) nozzle type as well as nozzle size have an important effect on droplet size as well as on velocity spectra. They found that droplet size and droplet velocity spectra were correlated to each other and they allow drift to affect the quantity and distribution of the deposit on the target. Damaged nozzles produced flow rates higher than the allowed limits of nozzle inspection regulations (Subr et al., 2015). The combination of the previous factors leads to incorrect application of pesticide dose consequently an uneven distribution of pesticide to the targeted crops but applying lower or much higher than the targeted rate as well.

4.5.2 Conclusions

The hypothesis tested in this chapter was: FA members are more likely to select an appropriate active ingredient and to apply pesticides correctly than non-FA members.

The objective of this chapter is to assess the ability of FA and nFA respondents to select and use pesticides properly. Survey findings were confirmed by spatial variability measurements. The results revealed no significant difference between FA and nFA respondents in ability to select the proper pesticides but there were significant differences between FA and nFA respondents in pesticide application (dose rate and PHI). Age, education level, pesticide experience, training, farm size and source of advice do not affect pesticide selection as they do with pesticide application. Excessive use of pesticide leads to health hazards for human and environment contamination, increased production cost and pest resistance development. There was no effect of the quality of pesticides analysed in the amount of pesticides (a.i.) used per unit area (application rates). Although, most of the nine samples of pesticides used in the FA and nFA farms were complying with global specifications (FAO), the amount of pesticides used still fluctuated lower and upper the recommended application rates. Number of treatments per season and mixing compatibility also need to be stated clearly on the labels. Heterogeneity of pesticide deposition confirm the variation and extensive use of pesticide application and it also indicated the need to assess sprayer types, calibration, nozzle type, droplet size, flow rate, and machine pressure to ensure suitability of the whole spraying system for effective spraying to control various pest and diseases attacking individual vegetable crop type at certain age stages. Introducing new pesticide application technologies is imperative action and panacea to mitigate the abuse of pesticides. Planning of education programs for governmental crop protection or extensions officials, retailers and farmers is essential to improve pesticide management scheme in the country.

Based on the findings, the hypothesis that FA farmers are more likely to choose appropriate pesticides and to apply them more correctly is rejected.

4.6 Recommendations

1. There is an urgent need to introduce holistic and attractive training programs on crop protection and pesticide application for all stakeholders including crop protection officials, extension services, pesticide retailers and farmers on the basis of which reliable, trustworthy communication channels between farmers and governmental extension services should be established.

2. There is also an urgent need to adopt/establish and implement integrated pest and disease management programmes for both FA and nFA farmers.

3. Given the exposure of operators to pesticides and the unsatisfactory spatial variability of current spraying methods, a programme to phase out such spraying methods is highly desirable. Monitoring of sprayer type, nozzle type and condition, droplet size, flow rate, and pressure should be encouraged and incentives to introduce new spraying technology that ensures lower use of pesticides with more even spatial distribution and operator safety.

4. Apply batch-to-batch pesticide analysis at the port of entry and screening the local manufactures and used pesticides to ensure their quality to fulfil global standards and specifications.

5. A programme to increase the public awareness about the use of pesticides and the proper ways to handle, use and store these chemicals.

6. Allowing and encouraging nFA farmers to join the FA or to establish an alternative farmer field school to improve their knowledge, attitudes and implementation of crop protection products in more efficient ways.

7. Enforcement of the pesticide law and its regulations to compel the farmers to use the pesticides in a proper way that ensure efficient application and reduce the abuse that may affect human and environmental health and ensure sustainability of agriculture in Oman.

8. There is a need to include basic information on the container's labels including number of treatments per season and compatibility of mixing the products.

4.7 References

Abadi, B. (2018) ‘The determinants of cucumber farmers’ pesticide use behavior in central Iran: Implications for the pesticide use management’, *Journal of Cleaner Production*., 205, pp. 1069-1081.

Abhilash, P. C. and Singh, N. (2009) ‘Pesticide use and application: An Indian scenario’, *Journal of Hazardous Materials*, 165, pp. 1-12.

Adejumo, O. A., Ojoko, E. A. and Yusuf, S. A. (2014) ‘Factors Influencing Choice of pesticides used by grain farmers in Southwest Nigeria’, *Journal of Biology, Agriculture and Healthcare*., 4, pp. 31-38.

Akter, M. Fan, L., Rahman, M. M., Geissen, V. and Ritsema, C. J. (2018) ‘Vegetable farmers’ behaviour and knowledge related to pesticide use and related health problems: A case study from Bangladesh’, *Journal of Cleaner Production.*, 200, pp. 122-133.

Alexandre, G. P., Aurora-Prado, M. S, Mariño, L. V. E., Singh, A. K., Leite, H. D., Kedor-Hackmann, E. R. M. and Santoro, M. I. R. M. (2016) ‘Simultaneous determination of abamectin homologs H2B1a and H2B1b in gel formulation by high performance liquid chromatography’, *Brazilian Journal of Pharmaceutical Sciences*, 52, pp. 509-516.

Al Zadjali, S., Morse, S., Chenoweth, J. and Deadman, M. (2014) ‘Factors determining pesticide use practices by farmers in the Sultanate of Oman’, *Science of the Total Environment*., 476-477, pp. 505-512.

Atreya, K., Sitaula, B. K., Johnsen, F. H. and Bajracharya, R. M. (2011) ‘Continuing issues in the limitations of pesticide use in developing countries’, *Journal of Agricultural and Environmental Ethics*, 24, pp. 49-62.

Bass, C. (2015) ‘The global status of insect resistance to neonicotinoid insecticides’, *Pesticide Biochemistry and Physiology*., 121, pp. 78-87.

Buhler, W. (2021) 'Understanding resistance', https://pesticidestewardship.org/resistance/understanding-resistance/ (Accessed on 16 June 2021).

Cameron, P. J. (2007) ‘Factors influencing the development of integrated pest management (IPM) in selected vegetable crops: A review’, *New Zealand Journal of Crop and Horticultural Science*, 35, pp. 365-384.

Damalas, C. A., Theodorou, M. G. and Georgiou, E. B. (2006) ‘Attitudes towards pesticide labelling among Greek tobacco farmers’, *International Journal of Pest Management,* 52, pp. 269-274.

Dekeyser, D. Foque, D., Duga, A. T., Verboven, P., Hendrickx, N. and Nuyttens, D. (2014) ‘Spray deposition assessment using different application techniques in artificial orchard trees’, *Crop Protection*, 64, pp. 187-197.

Chao, Z., Shi, G. Jian, S. and Rui-fa, H. (2015) ‘Productivity effect and overuse of pesticide in crop production in China’, *Journal of Integrative Agriculture*., 14, pp. 1903-1910.

Durmusoglu, E., Madanlar, N. and Weintraub, P. G. (2008) ‘Active ingredient contents of “me-too” registered abamectin products and differences in their efficacy on *Tetranychus cinnabarinus*’, *Phytoparasitica*, 36, pp. 231-241.

FAO (1991) ‘FAO Specifications for plant protection products’, p. 15.

FAO (1995) 'FAO Specifications for plant protection products: Metalaxyl (AGP:CP/329).

FAO (2017) 'FAO Spescifications and evaluations for agricultural pesticides: Deltamethrin'.

Ferguson, J. C., O'Donnell, C. C., Chauhan, B. S., Adkins, S. W., Kruger, G. R., Wang, R., Ferreira, P. H. U. and Hewitt, A. J. (2015) ‘Determining the uniformity and consistency of droplet size across spray drift reducing nozzles in a wind tunnel’, *Crop Protection*., 76, pp. 1-6.

Gautam, S., Schreinemachers, P., Nasir Uddin, M. and Srinivasan, R. (2017) ‘Impact of training vegetable farmers in Bangladesh in integrated pest management (IPM)’, *Crop Protection*., 102, pp. 161-169.

Gil, E., Escola` A., Rosell. J. R., Planas, S. and Val, L. (2007) ‘Variable rate application of plant protection products in vineyard using ultrasonic sensors’, *Crop Protection*, 26, pp. 1287-1297.

Gisi, U. and Leadbeater, A. (2010) ‘The challenge of chemical control as part of integrated pest management’, *Journal of Plant Pathology*, 92, pp. 11-16.

Grovermann, C., Schreinemachers, P. and Berger, T. (2013) ‘Quantifying pesticide overuse from farmer and societal points of view: An application to Thailand’, *Crop Protection.*, 53, pp. 161-168.

Halimatunsadiah, A. B. et al. (2016) ‘Application of pesticide in pest management: The case of lowland vegetable growers’, *International Food Research Journal*, 23, pp. 85-94.

Hashemi, S. M. and Damalas, C. A. (2011) ‘Farmers’ perceptions of pesticide efficacy: Reflections on the importance of pest management practices adoption’, *Journal of Sustainable Agriculture*, 35, pp. 69-85.

Jallow, M. F. A. et al. (2017) ‘Monitoring of pesticide residues in commonly used fruits and vegetables in Kuwait’, *International Journal of Environmental Research and Public Health*, 14, 833.

Jha, R. K. and Regmi, A. P. (2009) ‘Pesticide productivity and vegetable farming in Nepal’, *Environmental Valuation: In South Asia*, 43, pp. 115-140.

Khan, M. and Damalas, C. A. (2015) ‘Factors preventing the adoption of alternatives to chemical pest control among Pakistani cotton farmers’, *International Journal of Pest Management.*, 61, pp. 9-16.

Kwakye, M. O., Mengistie, B., Ofosu-Anim, J., Nuer, A. T. K. and Brink, P. J. V (2019) ‘Pesticide registration, distribution and use practices in Ghana’, *Environment, Development and Sustainability. Netherlands*, 21, pp. 2667-2691.

Lin, L., Yang, C., Peng, Z., Wang, M., Zeng, Z and Guo, H. (2013) 'Determination of imidacloprid, acetamiprid, thiabendazole and carbendazim residues in edible fungi by HPLC', *Advanced Materials Research*, 781, pp. 99-103.

Lucas, J. A., Hawkins, N. J. and Fraaije, B. A. (2015) 'The evolution of fungicide resistance, *Advances in Applied Microbiology*', 90, pp. 29-92.

Macharia, I., Mithöfer, D. and Waibel, H. (2013) ‘Pesticide handling practices by vegetable farmer in Kenya’, Environment, *Development and Sustainability*, 15, pp. 887-902.

Mengistie, B. T., Mol, A. P. J. and Oosterveer, P. (2017) ‘Pesticide use practices among smallholder vegetable farmers in Ethiopian Central Rift Valley’, *Environment, Development and Sustainability*, 19, pp. 301-324.

Miranda-Fuentes, A., Lizana, A. R., Gil, E., Aguera-Vega, J. and Gil-Ribes, J. A. (2015) ‘Influence of liquid-volume and airflow rates on spray application quality and homogeneity in super-intensive olive tree canopies’, *Science of the Total Environment.*, 537, pp. 250-259.

Mubushar, M., Aldosari, F. O., Baig, M. B., Alotaibi, B. M. and Khan, A. (2019) ‘Assessment of farmers on their knowledge regarding pesticide usage and biosafety’, *Saudi Journal of Biological Sciences.,* 26, pp. 1903–1910.

Hassen, N. S., Sidik, N. C. and Sheriff, J. M. (2014) ‘Advanced techniques for reducing spray losses in agrochemical application system’, *Life Science Journal*', 11, pp. 56-66.

Nath, R., Sukhadiya, D., Ojha, M., Tripathi, S. and Dashora, K. (2017) ‘Fabrication of controlled droplet application for efficient use of pesticides’, *International Research Journal of Engineering and Technology*(IRJET), 4, pp. 802-810.

Negatu, B., Kromhout, H., Mekonnen, Y. and Vermeulen, R. (2016) ‘Use of chemical pesticides in Ethiopia: A cross-sectional comparative study on knowledge, attitude and practice of farmers and farm workers in three farming systems’, *Annals of Occupational Hygiene*, 60, pp. 551-566.

Ngowi, A. V. F., Mbise, T. J., Ijani, A. S. M, London, L. and Ajayi, O. C. (2007) ‘Pesticides use by smallholder farmers in vegetable production in Northern Tanzania.’, *Crop protection,* 26, pp. 1617-1624.

Nuyttens, D., Baetens, K., De Schampheleire, M. and Sonck, B. (2007) 'Effect of nozzle type, size and pressure on spray droplet characteristics', *Biosystems Engineering,* 97, pp. 333-345.

Ngowi, A. V.F., Mbise, T. J., Ijani, A. S. M, London, L. and Ajayi, O. C. (2007) ‘Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects’, *Crop Protection*, 26, pp. 1617-1624.

Obana, H., Okihashi, M., Akutsu, K., Kitagawa, Y. and Hori, S. (2002) ‘Determination of acetamiprid, imidacloprid, and nitenpyram residues in vegetables and fruits by high-performance liquid chromatography with diode-array detection’, *Journal of Agricultural and Food Chemistry*, 50, pp. 4464-4467.

Okonya, J. S. and Kroschel, J. (2015) ‘A cross-sectional study of pesticide use and knowledge of smallholder potato farmers in Uganda’, *BioMed Research International*, 2015, pp. 1-9.

Oliver, M. A. and Webster, R. (2014) ' A tutorial guide to geostatistics: Computing and modelling variograms and kriging', *Catena*, 113, pp. 56-69.

Pauluhn, J. and Ozaki, K. (2015) ‘Transfluthrin: Comparative efficacy and toxicity of reference and generic versions’, *Regulatory Toxicology and Pharmacology*., 71, pp. 78-92.

Pergher, G. (2004) ‘Field evaluation of a calibration method for air-assisted sprayers involving the use of a vertical patternator’, *Crop Protection,* 23, pp. 437-446.

Qin, G., Keting Zou, K., Li, Y., Chen, Y., He, F. and Ding, G. (2016) ‘Pesticide residue determination in vegetables from western China applying gas chromatography with mass spectrometry’, Biomedical Chromatography, 30, pp. 1430-1440.

Rahman, S. (2016) ‘Jointness in farmers’ decision to apply pesticides in multiple crops and its determinants at the farm level in Bangladesh’, *International Journal of Pest Management*., 62, pp. 149-157.

Rajasekaran, A., Beneeta, T., Meeradas, K., Sajini, J. T. and Narayanan, S. (2013) ‘Analysis of emamectin benzoate residues in cauliflower using HPLC’, *Research Journal of Pharmacy and Technology,* 6, pp. 1157-1160.

Rijal, J. P., Regmi, R., Ghimire, R., Puri, K. D., Gyawaly, S. and Poudel, S. (2018) ‘Farmers’ knowledge on pesticide safety and pest management practices: A case study of vegetable growers in Chitwan, Nepal’, *Agriculture* (Switzerland), 8, 16.

Roten, R. L., Hewitt, A. J., Ledebuhr, M., Thistle, H., Connell, R. J., Wolf, T. M., Sankar, S. and Woodward, S. J. R. (2013) ‘Evaluation of spray deposition in potatoes using various spray delivery systems’, *New Zealand Plant Protection*, 66, pp. 317-323.

Sabur, S.A.; Molla, A. R. (2000) ‘Pesticide use, its impact on crop production and evaluation of IPM technologies in Bangladesh’, *Bangladesh Journal of Agricultural Economics*, 24, pp. 21-38.

Saleh Abbassy, M. M. (2017) ‘Farmer’s knowledge, attitudes and practices, and their exposure to pesticide residues after application on the vegetable and fruit crops. case study: North of delta, Egypt’, *Journal of Environmental & Analytical Toxicology*, 07, 510.

Silva, S. A., Alvarenga, C. B., Lima, J. S. S. and Silva, M. A. S. (2015) ‘Spatial quality assessment of pesticide applications using a cannon sprayer', *Engenharia na agricultura,* 4, pp. 418-428.

Sangchan, W., Hugenschmidt, C., Ingwersen, J., Schwadorf, K., Thavornyutikarn, P., Pansombat, K. and Streck, T. (2012) ‘Short-term dynamics of pesticide concentrations and loads in a river of an agricultural watershed in the outer tropics’, *Agriculture, Ecosystems and Environment.,* 158, pp. 1-14.

Schreinemachers, P., Chen, H., Nguyen, T. T. L., Buntong, B., Bouapao, L., Gautam, S., Le, N. T., Pinn, T., Vilaysone, P. and Srinivasan, R. (2017) ‘Too much to handle? Pesticide dependence of smallholder vegetable farmers in Southeast Asia’, *Science of the Total Environment,*, 593–594, pp. 470-477.

Schreinemachers, P., Sringarm, S. and Sirijinda, A. (2011) ‘The role of synthetic pesticides in the intensification of highland agriculture in Thailand’, *Crop Protection*., 30, pp. 1430-1437.

Sedlar, A. D. Bugarin, R. M., Nuyttens, D., Turan, J. J., Zoranovic, M. S., Ponjican, O. O. and Janic, T. V. (2013) ‘Quality and efficiency of apple orchard protection affected by sprayer type and application rate’, *Spanish Journal of Agricultural Research*, 11, pp. 935-944.

Sharifzadeh, M. S., Abdollahzadeh, G., Damalas, C. A. and Rezaei, R. (2018) ‘Farmers’ criteria for pesticide selection and use in the pest control process’, *Agriculture* (Switzerland), 8, pp. 1-16.

Sharma, D. R. (2015) ‘Use of pesticides and its residue on vegetable crops in Nepal’, *Journal of Agriculture and Environment,* 16, pp. 33-42.

Sherwood, S., Cole, D. C., Crissman, C. and Paredes, M. (2005) ‘From pesticides to people: Improving ecosystem health in the Northern Andes’, in the pesticide detox: Towards a more sustainable agriculture. Earthscan Publications Ltd, London, UK.

Shrestha, P., Koirala, P. and Tamrakar, A. S. (2010) ‘Knowledge, practice and use of pesticides among commercial vegetable growers of Dhading district, Nepal’, *Journal of Agriculture and Environment*, 11, pp. 95–100.

Subr, A. K., Sawa, J. and Parafiniuk, S. (2015) ‘Practical deviation in sustainable pesticide application process’, *Agriculture and Agricultural Science Procedia*, 7, pp. 241-248.

Sun, S., Hu, R., Zhang, C. and Shi, G. (2019) ‘Do farmers misuse pesticides in crop production in China? Evidence from a farm household survey’, *Pest Management Science*, 75, pp. 2133-2141.

Tadevosyan, A., Tadevosyan, N., Kelly, K., Gibbs, S. G. and Rautiainen, R. H. (2013) ‘Pesticide use practices in rural Armenia’, *Journal of Agromedicine*, 18, pp. 326-333.

Tan, D. N. (2021) ‘Current situation and awareness of pesticide abuse in agriculture in Vietnam’, *E3S Web of Conferences*, 234, pp. 1-4.

Tandi, T. E., Wook, C. J., Shendeh, T. T., Eko, E. A. and Afoh, C. O. (2014) ‘Small-scale tomato cultivators’ perception on pesticides usage and practices in Buea Cameroon’, *Health*, 6, pp. 2945-2958.

Tisdell, C. A., Auld, B. A. and Menz, K. M. (1984) ‘On assessing the value of biological control of weeds.’, *Protection Ecology,* 6, pp. 169-179.

Wise, J. C., Jenkins. P. E., Schilder, A. M. C., Vandervoort, C. and Isaacs, R. (2010) ‘Sprayer type and water volume influence pesticide deposition and control of insect pests and diseases in juice grapes’, *Crop Protection*., 29, pp. 378-385.

Xiao, J., Chen, L., Pan, F., Deng, Y., Ding, C., Liao, M., Su, X. and Cao, H. (2020) ‘Application method affects pesticide efficiency and effectiveness in wheat fields’, *Pest Management Science*, 76, pp. 1256-1264.

Yang, M., Zhao, X. and Meng, T. (2019) ‘What are the driving factors of pesticide overuse in vegetable production? Evidence from Chinese farmers’, *China Agricultural Economic Review,* 11. pp. 672-687.

Zhang, C., Hu, R., Shi, G., Jin, Y., Robson, M. G. and Huang, X. (2015) ‘Overuse or underuse? An observation of pesticide use in China’, *Science of the Total Environment.*, 538, pp. 1-6.

Zhu, W. and Wang, R. (2021) ‘Impact of farm size on intensity of pesticide use: Evidence from China’, *Science of the Total Environment.*, 753, pp. 1-6.

Chapter 5. Knowledge, perceptions and practices of health and safety measures for pesticides amongst vegetable farmers in Oman.

5.1 Summary

The objective of this chapter is to assess the knowledge, attitudes and practices of FA and nFA respondents in regard to health and safety measures while handling, mixing, spraying and disposing of the pesticides. Most of FA respondents (53%) realised that pesticides could cause adverse effects to humans and the environment, however, 61% of nFA respondents did not think that pesticides could cause any problems. Although, the majority of FA and nFA respondents claimed never to have observed any adverse effects on their health, some respondents (5% of FA and 9% of nFA) disclosed rare incidences of health problems on their bodies. One third of both FA and nFA were not wearing any personal protective equipment (PPE) while using pesticides so that there was no significant variation between FA and nFA groups in use of PPE. Most of the FA respondents (63%) revealed that they read the safety instructions as stated on the labels in comparison to 79% of nFA who never read the instructions. More than 90% of FA respondents were able to identify pictorial safety instructions with more than 80% of nFA who could correctly identify the need for proper spraying, gloves and boots. The study showed that there were 84 active ingredients used within FA and nFA farms with the insecticide, abamectin, the most frequently used. The use of “Me too” pesticides was reported within FA (54%) and nFA (66%) farms. The study revealed that there is a persistent need to design and implement health and safety awareness programmes for pesticide stakeholders in Oman to improve their ability towards safe use of pesticides and to avoid their exposure risks to these chemicals. Moreover, inviting the pesticide handlers to participate in workshops to discuss their perceptions with reference to health and safety measures and pesticide issues is a vital tool to mitigate the adverse impacts on humans and the environment.

Key words: Health and safety, pesticides and pesticides applicator

5.2 Introduction

Pesticides are still widely used and needed to control crop protection problems worldwide. The total import value of pesticides in Oman increased from 8 Million USD to 38 Million USD between 1990 and 2018 (FAO, 2018). Around 85% of the chemical pesticides are used to control various agriculture pests including insects, diseases and weeds (Kim et al., 2017). Besides the importance of pesticides in agricultural production, they also could impose harmful effects to humans and the environment. The World Health Organisation classified pesticide active ingredients based on their acute toxicity hazards into five main categories based on lethal dose to 50% (LD_{50}) of experimental rats (Table 5.1).

Table 5.1 Pesticide active ingredients acute toxicity classification based on their LD_{50} (WHO, 2009).

Class	Toxicity level	LD_{50} for the rat (mg AI/kg body weight)	
		Oral	Dermal
Ia	Extremely hazardous	< 5	< 50
Ib	Highly hazardous	5–50	50–200
II	Moderately hazardous	50–2000	200–2000
III	Slightly hazardous	Over 2000	Over 2000
U	Unlikely to present acute hazard	5000 or higher	

5.2.1 Pesticide toxicity to humans

There are many pathways by which pesticides can cause adverse effects to humans through the exposure process which could be dermal, oral, ocular and respiratory. It has been reported that pesticides can cause many health hazards to humans. The most reported common problems are dermal (Zhao, M.A., et al. 2016, Atabila et al., 2017 and Lehmann et al., 2018), respiratory (Fieten et al., 2009, Lu, 2009, Ye et al., 2013, De Jong et al., 2014, Matsukawa, et al., 2015, Raanan et al., 2015, Lytras et al., 2018 and ocular Memon et al., 2019). Many human ailments have been found to be associated with exposure to agricultural pesticides. The early symptoms of toxicity that may occur to pesticide applicators include headache, cough, asthma and breathing difficulties (Tsimbiri et al., 2015). In Thailand, many symptoms were reported after using pesticides included cramps (17%), nausea/vomiting (13.4%), blurry vision (23%), dizziness (26%) and sweating (34%) (Kongtip et al., 2018). In addition, pesticides may cause many longer-term chronic and sub-chronic health problems. According to Riaz et al. (2017), there was a correlation between the exposure of pesticides workers and susceptibility to tuberculosis and alterations in liver enzymes. Moreover, organochlorine pesticides were found to be associated with hormone-related cancer as a group and with prostate cancer specifically (Xu et al., 2010). In one of the worst scenarios and due to poisoning, pesticides caused the deaths of 23 farmers in Yavatmal District of Maharashtra State in the western region of India (Damalas and Koutroubas, 2018).

5.2.2 Pesticide toxicity to environment

According to Zhang et al. (2011), around 4.6 million tons of chemical pesticides are annually sprayed into the environment globally. There are currently about 500 pesticides with mass applications, of which organochlorine pesticides, some herbicides and the pesticides containing mercury, arsenic and lead are highly poisonous to the environment. Pesticides are known to be toxic contaminants to environment components such as soil, water, turf, fish, aquatic organisms, beneficial organisms, air, wildlife, animals and not-targeted organisms. In a study performed in central California coastal estuary, Smalling et al. (2013) documented high levels of pesticides in water, sediment and tissues of resident aquatic organisms. In addition, Taiwo (2019) reported high levels of organochlorine pesticides residues in fresh water and marine fish in many African countries. Bentazone, carbendazim, dimethoate, diuron, endosulfan, epoxyconazole, propanil, terbutryn and triazophos were reported in surface water and bifenthrin, chlorpyrifos, lambda cyhalothrin, cypermethrin, deltamethrin, diuron, endosulfan, permethrin, terbutryn and triazophos were found in sediment samples in Costa Rica (Carazo-Rojas et al., 2018). According to Simon-Delso et al. (2015), neonicotinoids are the most widely used pesticides worldwide. Neonicotinoids (mainly Imidacloprid) were also reported in soil, water and sediments samples in Belize (Bonmatin et al., 2019) and in aquatic organisms in Canada (Anderson, et al., 2015). The most affected non-target organisms of pesticides are honeybees (Connoly, 2013 and Baron et al., 2017). Honeybees are vital insects for pollination process in many crops as well as for vegetables and fruit. However, accidentally, they appear to be the most victims of pesticides applications especially the neonicotinoids (da SILVA et al., 2015, Codling et al., 2016 and Codling et al., 2017). Many countries have banned or restricted neonicotinoid pesticides for agriculture use because of their apparent impact on honeybees (*Apis mellifera*). Many reports have documented the hazards and risks of neonicotinoids pesticides to honeybees, honey, pollen and hives (da SILVA et al., 2015, Simon-Delso et al., 2015, Codling et al., 2016, Codling et al., 2017 and Karahan, et al., 2018). In Italy, out of the 66 most commonly used pesticides, chlopyrifos was most frequently reported (30%) in honeybee colonies as residues in pollen (Tosi et al., 2018). Honeybees are not only affected by neonicotinoids. Many other reports described the effects of different chemical groups to honeybees as well. Tosi and Nieh (2019) demonstrated increased mortality and abnormal behaviour in both in-hive and forager bees due to flupyradifurone and propiconazole spraying. Another study confirmed that flupyradifurone spraying increased mortality and premature onset of foraging in honeybees (Hesselbach et al., 2020). Other animals can also be contaminated with pesticides and, in a six-year study in Austria, carbamate insecticides were the most prominent agents in contamination of domestic animals and livestock (Wang et al., 2007).

5.2.3 Farmers' perspectives and perceptions on pesticide health and safety

The adverse effects of pesticides to humans and the environment depend on the farmer's or the pesticides applicator's knowledge, attitude and practice. Pesticide applicators may be exposed to contamination in different ways. Exposure to pesticides may occur during mixing, loading and spraying and the subsequent cleaning of equipment. In Southwest Ethiopia, it was found that out of 796 farmers, around 54% exhibited a positive attitude towards safe use of pesticides (Gesesew et al., 2016). Nevertheless, the authors reported that around 90% of farmers were exposed to pesticides. Participants reported ingestion (88.9%) and inhalation (90.4%) as possible mechanisms of pesticide exposure (Gesesew et al., 2016). A similar situation was also illustrated in Tanzania, where 93% (121 out of 130) of the farmers in Arumeru district in Arusha region appeared to exhibit or claim some symptoms of poisoning with pesticides in their lifetime and attended a health facility for treatment (Lekei et al., 2014). Bagheri et al. (2019) reported that farmers with good knowledge of the pesticide’s harmfulness were selecting low-risk pesticides and were using more personal protective equipment. They also concluded that farmers demonstrating better knowledge, attitude, and perceptions could protect themselves against the harmful effects of pesticides. Although 22% of 180 vegetable growers in Chitwan, Nepal, were illiterate, Rijal et al. (2018) found that 88% of them were aware of potential adverse effects of pesticides. The situation in Egypt was different and Abbassy (2017) demonstrated that despite the pesticide applicators knowing about the potential human health risks of pesticides, the precautionary measures taken against exposure were very rare and none of the investigated pesticide applicators wore any protective clothing during spraying. Moreover, in Morocco, it was also reported that unsafe pesticide handling was attributed to farmers low education levels and insufficient training (Berni et al., 2021). In a study conducted in Iran to map farmers' safety behaviour in disposal of spray solution leftovers, places for washing sprayers, disposal of rinsates, and use of PPE, Bagheri et al. (2021) concluded that improving farmers’ motivation and behaviour towards safe pesticide handling can be achieved though extension education.

5.2.4 Personal protective equipment (PPE)

Many workers are, therefore, not aware of the risks associated with the use of pesticides, and lack of education, training, experience and equipment for safely handling pesticides tends to be associated with increased health risks. Damalas and Abdollahzadeh (2016) concluded that many farmers (49%) showed potentially unsafe behaviour with respect to PPE use and most of the surveyed farmers reported low frequency of use for gloves, goggles, face mask, coveralls and respirators. In Thailand, Kongtip et al. (2018) reported that farmers who only grew vegetables had the lowest frequency of good exposure prevention practices including the use of

PPE. However, it was also demonstrated in Nepal that, despite poor knowledge of pesticide labels, 86% of vegetable growers used a form of PPE while handling pesticides (Rijal et al., 2018). This general awareness is good but inadequate because some pesticides are very toxic and require the use of multiple types of PPE for reducing exposure risk (Damalas and Koutroubas, 2016). In Vietnam, where the education level of the respondents was relatively high (83% middle school and above), around 81% of the pesticide applicators were using gloves during pesticide preparation and spraying. In addition, 93% of the applicators were using a face shield, mask and/or goggles during pesticide handling (Houbraken et al., 2016). The protection from pesticide exposure not only depends on PPE usage but also on the quality of manufacturing materials used in preparing the PPE and perhaps also in washing after use. In Uganda for example, although potato growers used many types of PPE, still they reported many health adverse effects (Okonya and Kroschel, 2015).

5.2.5 Label safety instructions

Safety instructions stated on a pesticide's container are very important for any pesticide applicator. These instructions explain all the safety precautions before, during and after spraying to save the applicator from any potential contaminations. In many countries, farmers do not read safety instructions before using pesticides. Mubushar et al. (2019) found that the majority of respondents (48%; n=205) in their survey did not read the instructions written on pesticide containers. Although the safety information on the labels is very useful, Damalas and Khan (2016) demonstrated that out of 318 cotton farmers, 73% of the farmers reported that they usually did not read these information. They also found that farmers who ignored reading the labels had significantly higher ages, lower education, more experience in chemical pest control, less income, and less training than farmers who did read the labels.

5.2.6 Pesticide health and safety measures (Oman context)

Health and safety measures of pesticide application in Oman have not been previously documented. According to the latest reports, the total number of people working in agriculture, forestry and fishing in Oman was 61,250 persons out of which 60,122 (98%) were expatriates (NCSI, 2020). Many of the agricultural workers are applying pesticides but few reports are published or reported on the adverse effects of these chemicals on pesticide handlers. Thacker et.al. (2000) reported a rudimentary use of PPE in vegetable farms in Oman and stated that only 20% of the farmers used gloves to mix the pesticides prior to application. Esechie and Ibitayo (2011) demonstrated some health symptoms in Al Batinah coastal area in Oman due to pesticide exposure such as skin irritation (70.3%), burning sensation (39.2%), headache (33.8%), vomiting (29.7%) and salivation (21.6%) amongst pesticide applicators (74) on the farms. They also suggested that more than 85% of the workers never or only sometimes wore goggles, overalls or masks.

Photograph 1. Workers spray pesticide using their own clothes to protect their body and face. The practice was frequently noticed in FA and nFA farms in Oman during the survey.

Although there were physical symptoms of some adverse effects of pesticides on workers, around 40% revealed that PPE was not supplied by their employers and about 16% of them thought that PPE was not necessary (Esechie and Ibitayo, 2011). The study demonstrated significant differences between PPE usage and adverse health symptoms such as headache, skin irritation, burning sensation and vomiting. Moreover, Al Zadjali et al. (2015) found that use of PPE was highest among respondents with more advanced educational backgrounds. Positive responses for glove and mask use while applying pesticides, were higher for owners and workers in FA farms compared to nFA farms. The previous studies showed that pesticide applicators were not in compliance with the safety instructions stated on the labels which may have led to increased chances of exposure to pesticides and adverse health consequences (Photograph 1). Thus, the objective of this chapter is to examine the awareness amongst farmers on the potential adverse effects of pesticides to human beings and the environment and to investigate the potential factors affecting farmers' perceptions and practices. The chapter also tries to answer the research question if farmers aware about the potential adverse effects of pesticide on human and the environment.

5.3 Materials and Methods

5.3.1 FA and non-FA surveys

Questionnaire-based surveys were conducted between 2015 and 2016 which covered 40 respondents from the Farmers' Association (FA) group and 120 respondents from non-farmers association (nFA) group. A detailed methodology of this chapter is explained in Chapter 2. Health and safety questions were administered in section six of the questionnaire. The data included the investigation on farmers' perceptions on potential risks of pesticides to human, animal and environment; safety precautions that farmers take or use during spraying; and checking if farmers read the safety instructions on the pesticide label before use. The pesticides survey also aimed to document the active ingredients, types, formulations and sources of the pesticides that farmers used for crop protection and these data were collected in section seven of the questionnaire (Appendix 2).

5.3.2 Statistical analysis

Mean ranks for non-parametric data from the survey questionnaires, including Likert scale questions, were compared using either the Mann-Whitney U-test for two groups or Kruskal-Wallis analysis for more than two groups (Lyman Ott, 1993). Within Kruskal-Wallis analysis, where significant differences in mean rank were indicated ($P \leq 0.05$), individual mean ranks were separated by using the z-value for significance threshold (Gwet, 2011) implemented within Microsoft Excel. In all analyses probability ($P \leq 0.05$) was considered to indicate significance in differences between rank averages or a significant correlation between variables.

5.4 Results

5.4.1 Possible pesticide risk knowledge level

FA and nFA farmer were investigated for their perceptions of the risks that pesticides may pose on humans, animals and environment. Generally, FA respondents showed better understanding of the potential risks of pesticides (Figure 5.1). For instance, Most of FA respondents believed pesticides posed risks to soil/water (53%), livestock (78%), wildlife (88%) and humans (90%) and only 5% did not think that pesticides carried any sort of risks. Conversely, a majority (60%) of the nFA respondents did not think that pesticides could carry any risk. Small proportions of nFA respondents believed that pesticides could cause any damage to soil/water (19%), animal (27%), wildlife (24%) or humans (35%) (P< 0.001, Appendix 26).

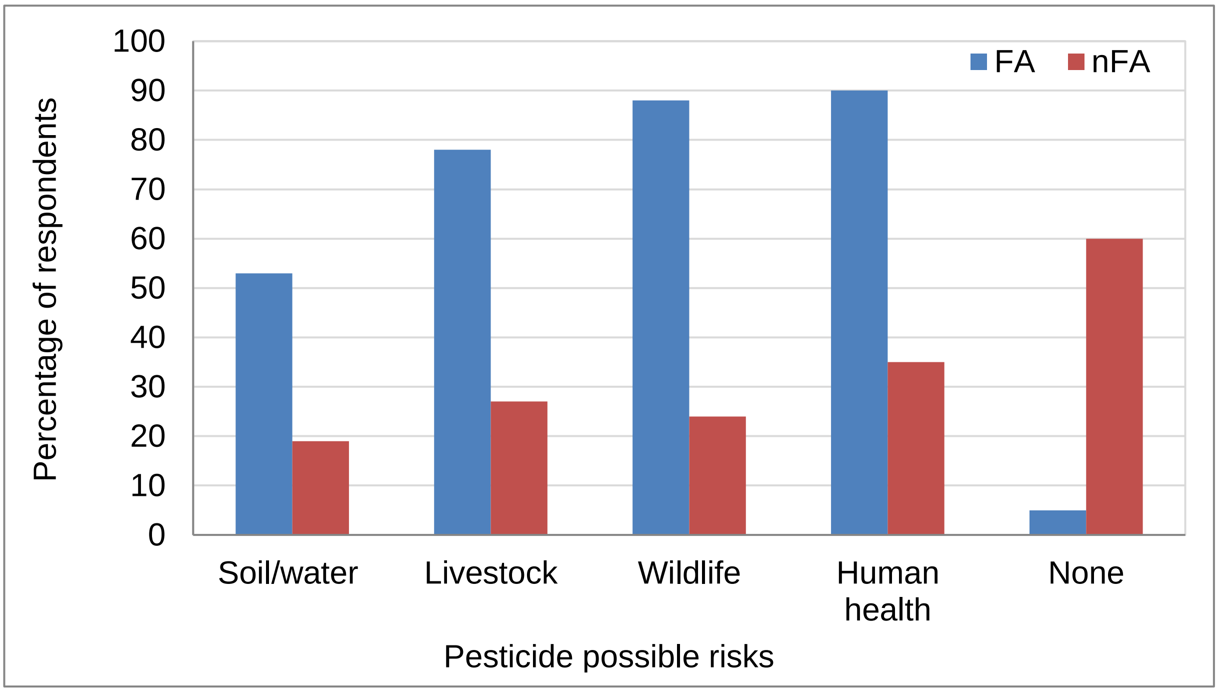


Figure 5.1 Percentages of FA (n=40) and nFA (n=120) respondents who believed that pesticides risked adverse effects to humans, animals and the environment.

5.4.1.1 Effect of respondent’s status, age, education level, pesticide experience, training and location on their response to the question “What possible risks do pesticides have?”

All respondents’ status of FA indicated better understanding of potential risks that pesticides may cause to human and the environment. For instance, around 86% of FA owners identified the possible risks in comparison to 77% of nFA owners (Table 5.2). The difference between FA and nFA tenants in ability to identify the possible risks reached 57% and for foremens reached 67.7% (P< 0.001, Appendix 26). Older and younger FA respondents (20-69 years) performed better than nFA respondents (20-69 years) in risks diagnosis. The differences were significant especially at the age category (30-39) years old of both groups (P< 0.001, Appendix 26). For all education levels, FA respondents showed high ability to identify the risks associated with pesticides than nFA respondents. Pairwise comparisons revealed significant differences in many levels but more specifically between grades 10-12 of both groups (P< 0.001, Appendix 26). Pesticide experience indicated positive effect on FA performance in risk identification than nFA respondents. The average percentage difference between categories reached 60% in some cases as in (1-9 years). The average percentage of positive responses to potential risks for other periods of experience varied between 30-50% between FA and nFA respondents (Table 5.2) which indicated significant difference and positive effect of pesticide experience on potential risks of pesticides (P< 0.001, Appendix 26). Although there was a significant effect of training on the performance of FA and nFA respondents in identifying risks associated with pesticides (P< 0.001, Appendix 26), but caution need to be taken due to small number of training programmes that both groups respondents attended (Table 5.2). The effect of locations on ability of respondents to recognise the potential risks of pesticides were reported mainly in Al Batinah north and south governates. For instance, 80% of FA respondents located in A’Suwaiq wilaya were able to identify the risks in comparison to 7.61% of nFA respondents in the same area (P< 0.001, Appendix 26). FA respondents located in Al Musanah reported 75% correct identification of pesticides potential risks in comparison to 13.6% of nFA respondents from the same location (Table 5.2).

Table 5.2 Numbers and averages (%) of FA (n=40) and nFA (n=120) respondents' status, age, education level, pesticide experience, training and location on their response to possible risks of pesticides to human and the environment.

No.	Variable											P
1	Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker				
	N	16	18	6	23	43	48	6				
	Average, %	85.9	70.8	83.3	77.2	14	15.6	0				< 0.001
2	Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	N	8	11	14	4	3	14	45	28	26	5	
	Average, %	67.6	69.7	75.3	65.8	63.3	25	21.1	34.8	21.2	60	< 0.001
3	Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		
	N	5	14	9	10	23	35	23	28	11		
	Average, %	63.3	62.6	75.9	87.3	23.9	18.6	27.2	18.8	70.5		< 0.001
4	Pesticide Experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49		
	N	15	13	9	3	52	35	20	9	4		
	Average, %	81.7	75.0	77.8	83.3	20.7	24.3	28.8	47.2	50.0		< 0.001

Table 5.2: continued																
5	Training	FA with training			FA without training			nFA with training				nFA without training				
	N	5			35			3				117				
	Average, %	100			75.7			58.3				25.2				< 0.001
6	Location	FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	
	N	8	25	14	11	23	4	15	4	14	8	3	3	3	8	
	Average, %	75	80	16.1	13.6	7.61	0	21.7	18.8	5.36	40.6	100	91.7	83.3	59.4	< 0.001

5.4.2 Farmers' responses regarding any adverse effects of pesticides on themselves

Most of FA (75%) and nFA (77%) respondents reported that they had never observed any adverse effects on their bodies while dealing with pesticides (Table 4.3). Twenty percent of FA and 10% of nFA respondents reported that they had "rarely" observed problems. Although the mean ranks of FA and nFA respondents (80.1 and 80.6, respectively) implies there was no significant difference between FA and nFA respondents in their experience of harmful effects of pesticides (P= 0.94, Appendix 27), it is however, alarming that 5% of FA respondents and 9.2% of nFA respondents had at least sometimes experienced such problems (Table 5.3) and revealed that sometimes they had observed adverse effect(s) of pesticides on their bodies during pesticides application while five nFA respondents usually or always had problems. The occurrence of these responses means that the absence of a statistically significant difference does not show there is "no effect" but simply that both groups of farmers encounter problems. Moreover, there is a very important qualitative difference in that no FA farmers "usually" or "always" experienced effects whereas five nFA farmers did (Table 5.3). So the absence of a significant overall effect masks the occurrence of a real difference. The admission by some that they did notice adverse effects on their bodies is not surprising since most of the pesticide applicators do not use PPE when they deal with pesticides (Photograph 2). What is surprising is that more did not report such effects. There was no significant effect of respondent's status, age, education levels, pesticide experience, training and location in the responses of respondents to the adverse effect of pesticides to themselves (P> 0.05, Appendix 27).

Table 5.3 Frequency, percentage and mean ranks of the FA and nFA respondents observing adverse effect(s) of pesticides on themselves. Although there was no overall significant difference between the two groups, there is a qualitative difference between the groups for the categories “usually” and “always”.

	FA (n=40)		nFA (n=120)	
	N	%	N	%
Never (1)	30	75	92	76.7
Rarely (2)	8	20	12	10
Sometimes (3)	2	5	11	9.2
Usually (4)	0	0	2	1.7
Always (5)	0	0	3	2.5
Mean rank	80.1		80.6	
P	0.944			

a)

b)

Photograph 2. Pesticide applicators, a: Pesticide applicator was preparing the pesticide solution for spraying without using any type of PPE increasing the likelihood of dermal toxicity; b: Pesticide applicator showing the effect of skin irritation of pesticides residues on his hand.

5.4.3 Use of special clothes (PPE) when applying pesticides

Here the term PPE is used with less precision as it simply relates to whether the respondents wore “special clothing” rather than purpose-designed PPE such as coveralls, water-proof gloves, rubber boots etc. With this caveat, over half (60%) of the FA respondents reported that they ***never or only rarely*** wore any PPE while applying pesticides compared to 37% of nFA (Table 5.4). Conversely, over half of nFA (51%) said they usually or always wore PPE when applying pesticides compared to only 28% of FA respondents (Table 5.5). Nevertheless, the implication that nFA respondents may have had a better understanding of the need for PPE when applying pesticides is not clearly supported by the Kruskal-Wallis test, where the difference in the mean rank of nFA and FA only suggests a weak trend (P= 0.17) and so the inference needs to be treated with caution (P= 0.17, Appendix 28). Moreover, there was no evidence that a respondent’s status, age, education level, pesticide experience or training had any significant effect on the responses to the using of PPE while handling and spraying pesticides (Appendix 28).

Table 5.4 Frequencies, percentages and mean ranks of FA and nFA responses to the question: "Do you wear any special clothes when applying pesticides?".

	FA (n=40)		nFA (n=120)	
	N	%	N	%
Never (1)	13	32.5	39	32.5
Rarely (2)	11	27.5	5	4.2
Sometimes (3)	5	12.5	15	12.5
Usually (4)	1	2.5	23	19.2
Always (5)	10	25	38	31.7
Mean rank	71.70		83.43	
P	0.17			

5.4.3.1 Type of safety equipment (PPE) used by farmers/workers while applying pesticides

Pesticide labels instruct users to protect all body parts by using an overall, gloves, mask, boots and protective glasses while dealing with pesticides. Results just presented show that many of those surveyed rarely or never wore wear any sort of personal protective equipment when they were applying pesticides (Table 5.5). For those who did, it was of interest to see what type of PPE they used. No single respondent from FA and only 2 nFA used all the PPE required for pesticide application (overall, gloves, mask, boots and glasses). At the other extreme, 37.5% of FA and around (6%) of nFA respondents simply used their own clothes (Table 5.5). Overalls were used by 20 and 7.5%, gloves by 12.5 and 10.9% of FA and nFA, respectively. Masks were in wider use either alone or in combination with other items, being worn by 37.5 and 53.4% of FA and nFA, respectively (Table 5.5).

Table 5.5 Numbers and percentages of PPE that FA and nFA respondents wear while applying pesticides.

	FA (n=40)		nFA (n=120)	
	N	%	N	%
Overall	2	5	2	1.7
Mask	6	15	17	14.2
Gloves	0	0	2	1.7
Own clothes	15	37.5	7	5.8
None	8	20	37	30.8
Overall + Mask	1	2.5	3	2.5
Mask + Gloves	1	2.5	8	6.7
Mask + Boot	1	2.5	0	0
Mask + Own clothes	1	2.5	38	31.7
Mask + Overall + Gloves	4	10	1	0.8
Mask + Overall + Boot	1	2.5	0	0
Overall + Gloves	0	0	2	1.7
Overall + Boot	0	0	1	0.8
All PPE items	0	0	2	1.7

5.4.4 Awareness and reading of label safety instructions before application

Safety instructions stated on the pesticide labels provide the applicators with important information about the chemical and how to deal safely with the pesticide before, during and after spraying. The label also provides the instructions on how to deal with any contamination or spillages while spraying and the antidotes to be taken in case of any poisoning cases. FA respondents were more likely to read the safety instructions with around 63% of them always reading them in comparison to 79% of nFA who say they never read them (Table 5.6). The mean rank of Likert-scale responses of nFA (67) indicates an increase towards score 1 (never reading the label) whereas the mean rank of FA respondents indicated an increase of the trend towards a score of 5 (always reading the label), the difference being significant ($P < 0.001$, Appendix 29).

Table 5.6 Numbers, percentages and mean ranks of FA and nFA respondents' responses to the question: "Do you read pesticide label safety instructions?"

	FA (n=40)		nFA (n=120)	
	N	%	N	%
Never (1)	7	17.5	95	79.2
Rarely (2)	2	5	1	0.83
Sometimes (3)	4	10	7	5.83
Usually (4)	2	5	8	6.67
Always (5)	25	62.5	9	7.50
Mean rank	121		67	
P	< 0.001			

5.4.4.1 Effect of respondent's status, age, education level, pesticide experience, training and location on their response to the question: "Do you read the safety instructions on pesticide labels before using them?"

There were significant effects of respondent's status, age, education level, pesticide experience and training regarding their reading safety instructions stated on the pesticide label (P< 0.05, Table 5.7). Owners of FA (75%) and nFA (35%) groups revealed the highest positive responses "always" amongst respondents. Foremen of FA (50%) revealed the lowest negative "never" response. Tenant (95%), foreman (94%) and worker (100%) of nFA indicated the lowest negative responses "never". However, the effect of status of the respondents was highly significant (P< 0.001, Appendix 29). The pairwise comparisons indicated that owners and tenants of FA were better in reading label safety instructions than tenants, foremen and workers of nFA (P< 0.001, Appendix 29). The younger FA respondents (20-29 years old) revealed better (always) responses (75%) in comparison to nFA respondents of the same age who showed high proportion (93%) that "never" read the safety instructions (P< 0.001, Table 4.7 and Appendix 29). The FA respondents who finished higher education level performed positive (always) responses (80%) towards reading safety instructions than nFA (36%) respondents of the same education level (Table 5.7). Pairwise comparison revealed that FA respondents with (grade 10-12) and (higher) education levels were significantly better than nFA respondents with (none, elementary, grade 7-9 and grade 10-12) education levels (P< 0.001, Appendix 29). As the years of experience of FA respondents increased (1-39 years), the positive responses to reading safety instructions increased too (56% to 100%). Although the trend was increasing for nFA respondents for the same years of experience (1-39 years), but the rate of increase was lower (2% to 10%) than FA (Table 5.7). However, the significant difference between FA and nFA respondents in reading the safety instructions was more obvious in the years of experience (1-9) for both groups (P< 0.001, Appendix 29). All of the trained FA respondents "always" read the safety instructions in comparison to 33% of trained nFA respondents (Table 5.7). However, 20% of untrained FA respondents "never" read the safety instructions in comparison to 80% of untrained nFA respondents (P< 0.001, Appendix 29). Respondents of FA and nFA from same wilaya (A'Suwaiq) revealed a significant difference but not between governates (P< 0.001, Appendix 29).

Table 5.7 Numbers and percentages of FA (n=40) and nFA (n=120) respondents' status, age, education level, pesticide experience, training and location in response to reading the label safety instructions before using them.

Variable*		Average, %										P**
Status		FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker				< 0.001
	N	16	18	6	23	43	48	6				
	Never (1)	0	22.2	50	13	95.3	93.8	100				
	Rarely (2)	12.5	0	0	0	2.3	0	0				
	Sometimes (3)	6.25	5.56	33.3	17.4	2.3	4.17	0				
	Usually (4)	6.25	0	16.7	34.8	0	0	0				
	Always (5)	75	72.2	0	34.8	0	2.08	0				
Age		FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	< 0.001
	N	8	11	14	4	3	14	45	28	26	5	
	Never (1)	12.5	36.4	14.3	0	0	92.9	88.9	64.3	80.8	40	
	Rarely (2)	0	0	0	25	33.3	0	0	3.57	0	0	
	Sometimes (3)	12.5	0	14.3	25	0	0	0	7.14	11.5	20	
	Usually (4)	0	0	7.14	25	0	0	8.89	7.14	0	40	
	Always (5)	75	63.6	64.3	25	66.7	7.14	2.22	17.9	7.69	0	
Education level		FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		< 0.001
	N	5	14	9	10	23	35	23	28	11		
	Never (1)	40	28.6	0	10	82.6	91.4	78.3	85.7	18.2		
	Rarely (2)	20	0	0	0	0	0	0	0	9.09		
	Sometimes (3)	0	14.3	11.1	10	8.70	5.71	8.70	0	9.09		
	Usually (4)	20	0	11.1	0	4.35	2.86	8.70	3.6	27.3		
	Always (5)	20	57.1	77.8	80	4.35	0	4.35	10.7	36.4		

Table 5.7: continued																
Variable		Average, %														P
Pesticides Experience		FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49						< 0.001
	N	15	13	9	3	51	35	19	10	4						
	Never (1)	18.8	30.8	0	0	96.1	71.4	79	50	25						
	Rarely (2)	6.25	0	11.1	0	0	2.86	0	0	0						
	Sometimes (3)	6.25	0	33.3	0	0	8.57	5.26	10	50						
	Usually (4)	6.25	7.69	0	0	1.96	5.71	5.26	30	0						
	Always (5)	56.3	61.5	55.6	100	1.96	11.4	10.5	10	25						
Training		FA with training			FA without training			nFA with training			nFA without training					< 0.001
	N	5			35			3			117					
	Never (1)	0			20			33.3			81					
	Rarely (2)	0			5.71			0			0.862					
	Sometimes (3)	0			11.4			33.3			5.17					
	Usually (4)	0			5.71			0			6.03					
	Always (5)	100			57.1			33.3			6.9					
Location		FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	< 0.001
	N	8	25	14	11	23	4	15	4	14	8	3	3	3	8	
	Never (1)	37.5	16	92.9	81.8	87.0	100	100	100	100	75	0	0	33.3	75	
	Rarely (2)	0	8	0	0	4.35	0	0	0	0	0	0	0	0	0	
	Sometimes (3)	0	4	0	9.09	0	0	0	0	0	12.5	33.3	33.3	33.3	0	
	Usually (4)	0	8	7.14	0	0	0	0	0	0	12.5	33.3	66.7	0	0	
	Always (5)	62.5	64	0	9.09	8.7	0	0	0	0	0	33.3	0	33.3	25	

* Variables with less than three records were excluded. **For statistical differences between individual variables, refer to appendices (4.16 – 4.21).

5.4.5 Safety precautions other than using PPE while dealing with pesticides.

Many respondents revealed a significant lack of safety awareness regarding pesticides immediately after application although some did take additional precautions over and above those stated on the labels. For example, about 23% and 18% of FA and nFA respondents, respectively, did not allow entry to their fields after spraying. Nevertheless, most FA (75%) and nFA (80%) did not practise any supplementary safety precautions (Table 5.8).

Table 5.8 Numbers and percentages of FA and nFA respondents using safety precautions other than PPE while or immediately after applying pesticides.

	FA (n=40)		nFA (n=120)	
	N	%	N	%
No field entry	9	22.5	22	18.3
Move livestock away	1	2.50	1	0.83
None	30	75	97	80.8

5.4.6 Ability to identify pictogram symbols

In general, FA respondents better understood the pictogram safety symbols which are printed on the lower part of pesticide labels than nFA respondents. More than 90% of FA respondent were able to identify the meaning of five out of seven symbols (Figure 5.2). Around 40 - 45% of FA respondents were able to identify the symbols indicating the need for proper storage and spraying techniques. More than 80% of nFA respondents reported correct identification of proper spraying and the need to wear gloves and boots. Fifty to 58% of nFA respondents were able to identify the face shield and the need to wash after spraying. Only 11% of nFA respondents were able to identify the need for proper storage correctly. However, an average of 80% of FA respondents were able to identify the seven safety symbols correctly in comparison to 55% of nFA respondents (P< 0.001, Appendix 30)

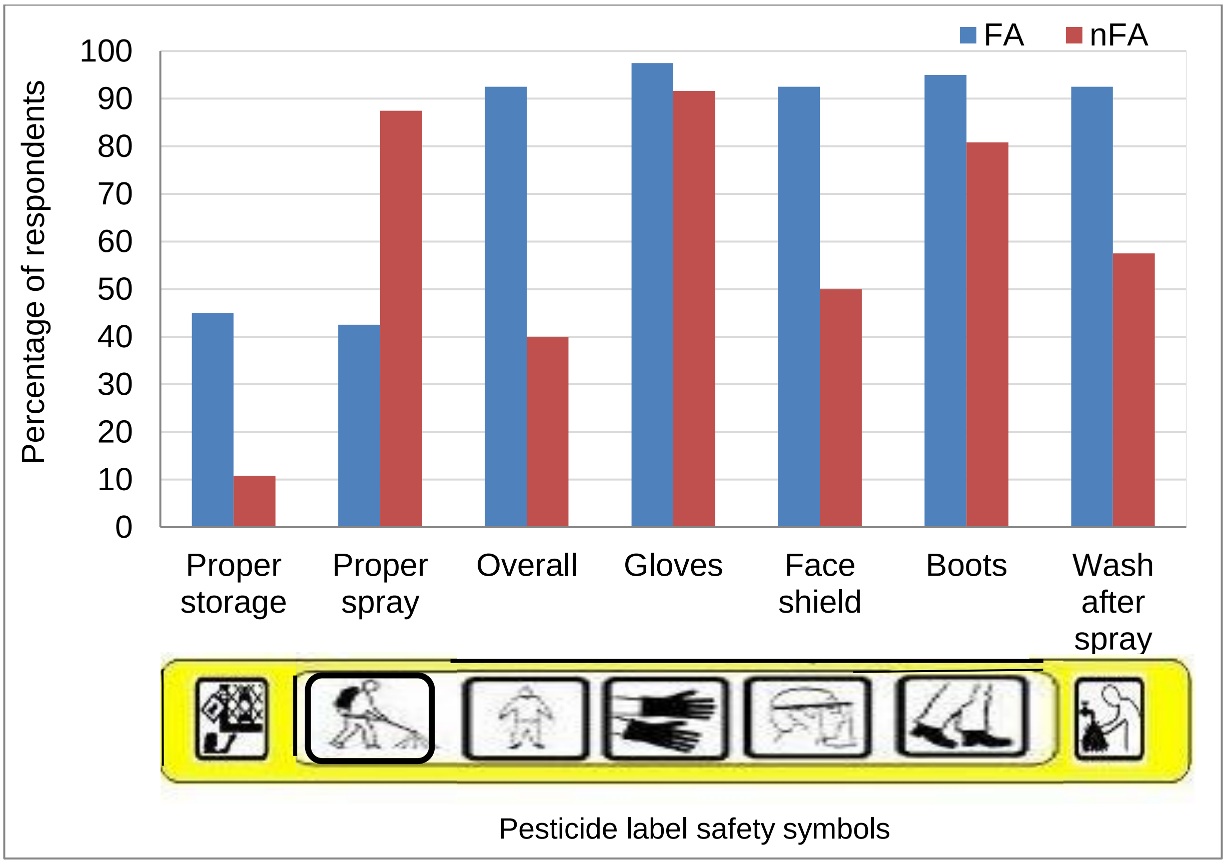


Figure 5.2 Percentages of FA (n=40) and nFA (n=120) respondents who were able to identify safety symbols drawn on pesticide labels.

5.4.6.1 Effect of respondent's status, age, education level, pesticides experience, training and locations on their response to the question "Do you understand what any of the pictogram safety symbols mean?"

In general, FA respondents revealed better identification of label safety symbols than nFA respondents for all variables (Table 5.9). For instance, FA owners were better able to identify safety symbols (85.7%) than owners of nFA (63.4%). The same trend was true for FA tenants (77.8%) and foremen (69%) in comparison to nFA tenants (47.8%) and foremen (57.1%). The pairwise comparisons revealed that the difference was mainly between tenants of FA and nFA (P< 0.001, Appendix 30). FA respondents aged from 20 to 69 years were better able to identify the seven safety pictograms than nFA respondents. The difference was more obvious between FA respondents aged 20-29 years (71.4%) and 30-39 years (83.1%) in comparison to nFA respondents (34.7%) and 48.3%) of the same age categories (P< 0.001, Appendix 30). There was a positive association of the education level on FA and nFA respondents on their ability to identify the safety symbols. The FA respondents who had finished grade 7-9 (79.6%) and grade 10-12 (88.9%) showed a significant difference from nFA respondents with the same education levels (P< 0.001, Appendix 30). The FA respondents who had 20-29 years of pesticide experience were best at identifying the label safety symbols (85.7%) while nFA respondents who had 40-49 years' experience performed better (67.9%, Table 5.9). Pairwise comparisons indicated significant differences between FA and nFA respondents for pesticide experience periods of 1-9, 10-19 and 20-29 years (P< 0.001, Appendix 30). In terms of location, the largest difference between FA (78.9%) and nFA (48.7%) respondents was located in A'Suwaiq wilaya (P< 0.001, Appendix 30).

Table 5.9 Numbers and percentages of FA (n=40) andnFA (n=120) respondents' status, age, education level, pesticide experience, training and location on their response to identify pesticie label safety pictogram symbols.

No.	Variable											P
1	Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker				
	N	16	18	6	23	43	48	6				
	Average, %	85.7	77.8	69	63.4	47.8	57.1	42.9				< 0.001
2	Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	N	8	11	14	4	3	14	45	28	26	5	
	Average, %	71.4	83.1	76.5	64.3	81.0	34.7	48.3	56.1	50.0	54.3	< 0.001
3	Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		
	N	5	14	5	10	23	35	23	28	11		
	Average, %	71.4	79.6	88.9	77.1	37.9	50.2	52.2	49	62.3		< 0.001
4	Pesticide Experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49		
	N	15	13	9	3	52	35	21	9	4	15	
	Average, %	79	76.9	85.7	76.2	42	55.9	48.6	55.6	67.9		< 0.001

* Variables with less than three records were excluded. ** For statistical analysis within individual variables, refer to appendix (4.5).

<table>
<tr><th colspan="17">Table 5.9: continued</th></tr>
<tr><td rowspan="3">5</td><td>Training</td><td colspan="3">FA
with training</td><td colspan="3">FA
without training</td><td colspan="4">nFA
with training</td><td colspan="4">nFA
without training</td><td></td></tr>
<tr><td>N</td><td colspan="3">5</td><td colspan="3">35</td><td colspan="4">3</td><td colspan="4">117</td><td></td></tr>
<tr><td>Average, %</td><td colspan="3">65.7</td><td colspan="3">81.6</td><td colspan="4">52.4</td><td colspan="4">49</td><td>< 0.001</td></tr>
<tr><td rowspan="3">6</td><td>Location</td><td>FA Al-Musanah</td><td>FA A’Suwaiq</td><td>nFA Barka</td><td>nFA Al-Musanah</td><td>nFA A’Suwaiq</td><td>nFA Saham</td><td>nFA Sohar</td><td>nFA Liwa</td><td>nFA Shinas</td><td>nFA Mhadah</td><td>nFA Ibri</td><td>nFA Bahla</td><td>nFA Bidiyah</td><td>nFA Al-Kamel</td><td></td></tr>
<tr><td>N</td><td>8</td><td>25</td><td>14</td><td>11</td><td>22</td><td>4</td><td>15</td><td>4</td><td>14</td><td>8</td><td>3</td><td>3</td><td>3</td><td>8</td><td></td></tr>
<tr><td>Average, %</td><td>76.8</td><td>78.9</td><td>51.0</td><td>45.5</td><td>48.7</td><td>39.3</td><td>48.6</td><td>35.7</td><td>43.9</td><td>50.0</td><td>61.9</td><td>52.4</td><td>47.6</td><td>42.9</td><td>< 0.001</td></tr>
</table>

5.4.7 Banned and restricted pesticides

The table below shows that only 12.5% of FA and 5% of nFA respondents have been contacted by the Ministry of Agriculture and Fisheries and Water Resources (MAFWR) to inform them about the pesticides that are allowed and not allowed to be used in the country (Figure 5.3).

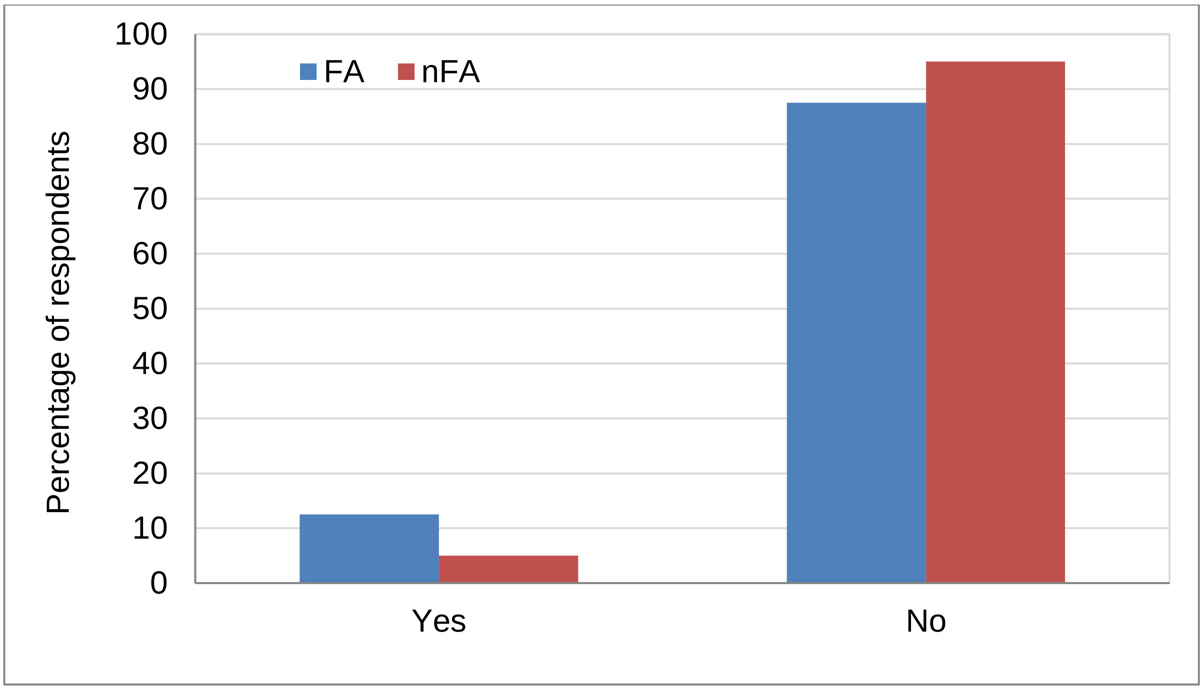


Figure 5.3 Percentage of FA (n=40) and nFA (n=120) respondents who were contacted or not contacted by MAFWR to be informed of allowed and not allowed pesticides (P> 0.05. Appendix 31).

5.4.8 Range of pesticides used in the farms

5.4.8.1 Pesticide distribution based on legal status and WHO toxicity classification by hazard.

Eighty-three active ingredients were identified as being stored and used in FA and nFA respondents' farms. Abamectin (insecticide/acaricide) was the most frequent active ingredient used on both FA and nFA farms (12 and 18.7%, respectively) followed by the fungicides, cymoxanil and metalaxyl (fungicides) on 5.4% of FA farms and acetamiprid (10.7%), emamectin benzoate (9.8%) and deltamethrin (8.4%) on nFA. The inventories showed that there were two active ingredients that had been banned according to the executive regulation of the pesticides law in Oman which was issued by MAFWR in 2012. These two were 2,4-D (herbicide) and dimethoate (insecticide) and both chemicals were found in nFA farms (Table 5.10). Moreover, the survey showed that seven restricted active ingredients were used in FA and nFA farms. Two restricted active ingredients were used in FA farms (Methomyl and Lambda-cyhalothrin) and seven (Cadusafos, Chlorpyrifos, Cypermethrin, Imidacloprid, Lambda-cyhalothrin, Methomyl and Methyl bromide) in nFA farms. Four active ingredients (abamectin, beta-cyfluthrin, cadusafos and methomyl) belonging to highly hazardous active ingredients (Ib class) of the WHO classification were found in FA and nFA farm stores (Table 5.10).

Table 5.10 Active ingredients (AI) expressed as a percentage of the total number of the 484 and 786 AIs found respectively in the pesticides stores of 40 FA and 120 nFA farms, along with the AIs legal status in Oman and the WHO's acute toxicity classification (WHO, 2009). Banned and restricted chemicals are listed first. Allowed chemicals are then ranked by percentage across all farms.

Uses: A: acaricide; F: fungicide; G: growth regulator; H: herbicide; I: insecticide; N: nematicide; R: rodenticide; S: sterilant

Active ingredient	Use	All farms	FA	nFA	Legal status*	WHO class**
		%				
Dimethoate	I	0.5	0.0	0.5	Banned	II
2.4-D	H	0.1	0.0	0.1	Banned	II
Methomyl	I	2.3	1.2	1.1	Restricted	Ib
Chlorpyrifos	I	0.4	0.0	0.4	Restricted	II
Cypermethrin	I	0.4	0.0	0.4	Restricted	II
Cadusafos	I	0.3	0.0	0.3	Restricted	Ib
Lambda-cyhalothrin	I	0.3	0.2	0.1	Restricted	II
Imidacloprid	I	0.1	0.0	0.1	Restricted	II
Methyl bromide***	F	0.1	0.0	0.1	Restricted	II
Abamectin	I/A	30.7	12.0	18.7	Allowed	Ib
Acetamiprid	I	15.9	5.2	10.7	Allowed	II
Deltamethrin	I	12.9	4.5	8.4	Allowed	II
Emamectin benzoate	I	12.7	2.9	9.8	Allowed	II
Metalaxyl	F	8.6	5.4	3.2	Allowed	II
Difenoconazole	F	7.4	5.2	2.2	Allowed	II
Copper oxychloride	F	7.2	5.2	2.0	Allowed	II
Cymoxanil	F	6.4	5.4	1.0	Allowed	II
Azoxystrobin	F	5.8	4.5	1.3	Allowed	U
Famoxadone	F	5.5	4.5	1.0	Allowed	U
Propamocarb hydrochloride	F	5.3	3.1	2.2	Allowed	U
Fosetyl-aluminium	F	4.9	3.1	1.8	Allowed	U
Malathion	I	4.3	2.3	2.0	Allowed	III
Thiophanate-methyl	F	4.2	1.9	2.3	Allowed	U
Benalaxyl	F	3.4	2.5	0.9	Allowed	III
Oxymatrine	I	3.2	2.1	1.1	Allowed	NL
Thiamethoxam	I	3.1	1.2	1.9	Allowed	II
Flutriafol	F	3.1	2.7	0.4	Allowed	II
Carbendazim	F	3	0.6	2.4	Allowed	U
Chlorantraniliprole	I	3	1.9	1.1	Allowed	U
Acrinathrin	I/A	2.8	1.9	0.9	Allowed	U
Iprodione	F	2.7	1.7	1.0	Allowed	III
Spinosad	I	2.4	2.1	0.3	Allowed	III
Pyridaben	I	2.1	0.8	1.3	Allowed	II
Copper hydroxide	F	1.7	0.8	0.9	Allowed	II

Lufenuron	I	1.7	0.6	1.1	Allowed	III
Thiocyclam hydrogen oxalate	I	1.7	1.2	0.5	Allowed	II
Cyromazine	I	1.5	0.6	0.9	Allowed	III
Dinotefuran	I	1.5	0.6	0.9	Allowed	III
Propineb	F	1.3	0.4	0.9	Allowed	U
Sulphur	F	1.3	0.0	1.3	Allowed	III
Pyriproxyfen	I	1.3	1.2	0.1	Allowed	U
Micronzed sulphur	F	1.3	0.0	1.3	Allowed	Ib
Buprofezin	I	1.2	0.6	0.6	Allowed	III
Fenpyroximate	I	1.2	0.8	0.4	Allowed	II
Mandipropamid	F	1.2	0.4	0.8	Allowed	III
Pirimiphos-methyl	I	1.1	0.8	0.3	Allowed	II
Fenitrothion	I	1.1	0.8	0.3	Allowed	II
Beta-cyfluthrin	I	1	0.6	0.4	Allowed	Ib
Bifenazate	A	1	0.6	0.4	Allowed	U
Indoxacarb	I	1	0.0	1.0	Allowed	II
Copper sulphate	F	0.9	0.6	0.3	Allowed	II
Etofenprox	I	0.9	0.0	0.9	Allowed	U
Milbemectin	I	0.9	0.8	0.1	Allowed	NL
Fenvalerate	I	0.9	0.6	0.3	Allowed	II
Thiacloprid	I	0.8	0.4	0.4	Allowed	II
Teflubenzuron	I	0.8	0.8	0.0	Allowed	III
Dimethomorph	F	0.6	0.0	0.6	Allowed	III
Trifloxystrobin	F	0.6	0.6	0.0	Allowed	U
Esfenvalerate	I	0.5	0.2	0.3	Allowed	II
Hymexazol	F	0.5	0.0	0.5	Allowed	III
Pyraclostrobin	F	0.5	0.0	0.5	Allowed	U
Diafenthiuron	I	0.4	0.4	0.0	Allowed	III
Mesosulfuron-methyl	H	0.4	0.0	0.4	Allowed	III
Glyphosate	H	0.3	0.2	0.1	Allowed	III
Tebuconazole	F	0.3	0.0	0.3	Allowed	II
Clethodim	H	0.3	0.0	0.3	Allowed	NL
Bordeaux mixture	F	0.3	0.0	0.3	Allowed	U
Acequinocyl	A	0.3	0.2	0.1	Allowed	NL
Chromafenozide	I	0.2	0.2	0.0	Allowed	NL
Tolclofos-methyl	F	0.2	0.2	0.0	Allowed	U
Pymetrozine	I	0.2	0.2	0.0	Allowed	U
Potassium salts of fatty acids	I/H/F	0.2	0.2	0.0	Allowed	II
Ethephon	G	0.1	0.0	0.1	Allowed	III
8-hydroxyquinoline	F	0.1	0.0	0.1	Allowed	NL
Fenoxaprop-p-ethyl	H	0.1	0.0	0.1	Allowed	III
Bromopropylate	A	0.1	0.0	0.1	Allowed	U
Geraniol	I	0.1	0.0	0.1	Allowed	NL
Naphthyl acetic acid	G	0.1	0.0	0.1	Allowed	III

Bacillus thuringiensis	I	0.1	0.0	0.1	Allowed	III
Phenthoate	I	0.1	0.0	0.1	Allowed	III
Spinetoram	I	0.1	0.0	0.1	Allowed	U
Metaflumizone	I	0.1	0.0	0.1	Allowed	U
Triglycerides	Adjuvant	0.1	0.0	0.1	Allowed	NL
*According to the updated pesticide executive regulation number 41/2012 issued by MAFWR.						
**WHO classification: Ia=Extremely hazardous, Ib=Highly hazardous, II=Moderately hazardous, III=Slightly hazardous, U=Unlikely to present acute hazard and NL= Not classified (WHO, 2009).						
***The use and production of methyl bromide is prohibited or severely restricted by the Montreal Protocol on Substances that Deplete the Ozone Layer (see https://www.informea.org/en/treaties/montreal-protocol), which entered into force on 1 January 1989 (WHO, 2019).						

Although the majority of the pesticides found in the FA and nFA respondents' farms were legal, some illegal and restricted pesticides were also found (Photograph 3; Table 4.10). The photos below showed there was illegal use of banned, restricted and unknown pesticides to control various crop pest problems by a few FA and nFA respondents.

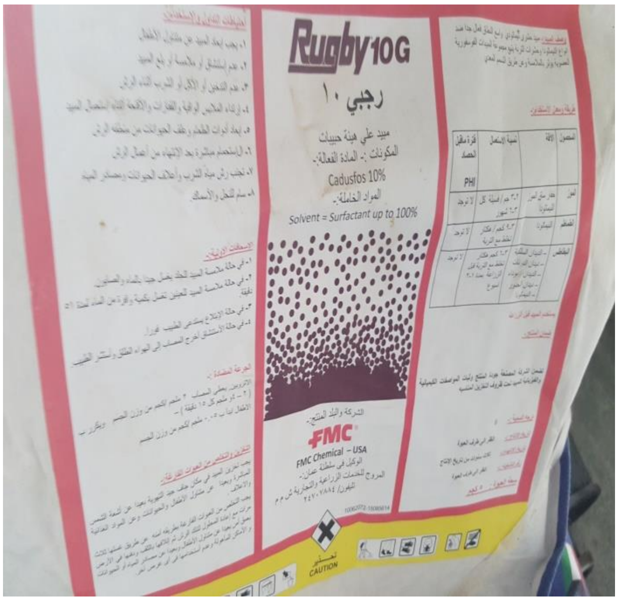
1. Banned pesticides

a) 2,4-D

b) Dimethoate

2. Restricted pesticides

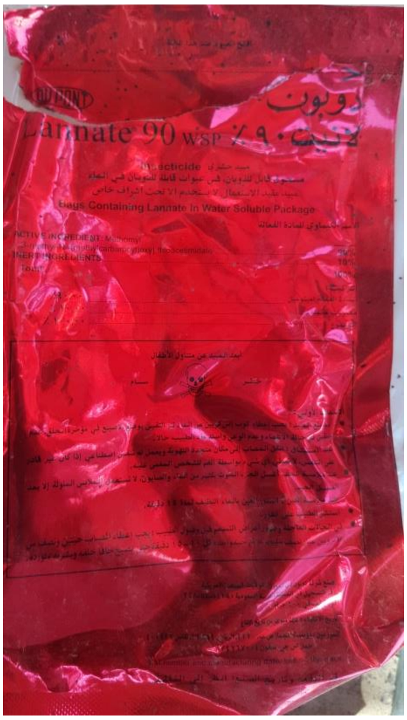
c) Cadusafos



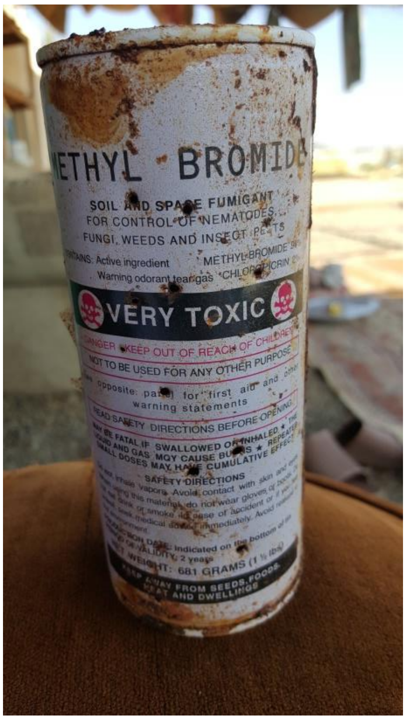
d) Cypermethrin

e) Imidacloprid

f) Methomyl



g) Methyl bromide



3. Unknown pesticides

Photograph 3. Banned (a and b), restricted (c, d, e, f and g) and unknown pesticides found in use on FA and nFA farms in Oman, under the 2012 Pesticides Executive Regulation of Pesticides Law. (27th August 2016)

5.4.8.2 Pesticide distribution based on chemical group

The pesticide distribution survey showed that there were 42 chemical groups in total (Table 5.11). Predominant chemical groups amongst FA were micro-organism derived (17.3%), pyrethroid (7.9%), triazole (7.9%) and neonicotinoid (7.4%). The most frequent chemical groups reported within nFA farms were micro-organism derived (28.2%), neonicotinoid (14%), pyrethroid (11.3%) and inorganic compound (5.8%). Organophosphate constituted 6.9% of the pesticides recorded at FA respondent farms while these were found in lower quantities (5.6%) in nFA farms. Likewise, 4.6% pesticides were recorded from the carbamates group in FA farms and 4.1% within nFA. However, the high percentage of micro-organism derived pesticides used in FA and nFA farms indicated better understanding of the respondents to the safer products (Table 5.11).

Table 5.11 Percentage of the active ingredients found in the FA (n=40) and nFA (n=120) farms based on their chemical groups.*

Chemical group	All farms			FA		nFA	
	Rank	N	%	N	%	N	%
Micro-organism derived	1	313	24.1	86	17.3	227	28.2
Neonicotinoid	2	147	11.3	36	7.4	111	14
Pyrethroid	3	130	10.0	39	7.9	91	11.3
Inorganic compound	4	79	6.1	32	6.5	47	5.8
Organophosphate	5	79	6.1	34	6.9	45	5.6
Triazole	6	62	4.8	39	7.9	23	2.9
Carbamate	7	56	4.3	23	4.6	33	4.1
Benzimidazole	8	51	3.9	12	2.4	39	4.8
Phenylamide	9	51	3.9	26	5.2	25	3.1
Strobilurin	10	39	3.0	25	5.0	14	1.7
Oxazole	11	34	2.6	22	4.4	12	1.5
Cyanoacetamide oxime	12	34	2.6	26	5.2	8	1.0
Unclassified	13	34	2.6	18	3.6	16	2.0
Plant derived	14	24	1.8	10	2.0	14	1.7
Acylamino acid	15	19	1.5	12	2.4	7	0.9
Anthranilic diamide	16	18	1.4	9	1.8	9	1.1
Benzoylurea	17	16	1.2	7	1.4	9	1.1
Dicarboximide	18	16	1.2	8	1.6	8	1.0
Pyridazinone	19	14	1.1	4	0.8	10	1.2

* For the rest of AIs found in FA and nFA farms refer to appendix 32.

5.4.8.3 Pesticide distribution based on targeted pests and diseases

Most of the pesticides found and used in FA farms were fungicides (40.9%) which were slightly more common than insecticides (39.5%). Acaricides were reported as the third predominant pesticides reported within FA farms (Figure 5.4). Insecticides were reported to be used frequently by nFA respondents and comprised 48.5%, followed by fungicides (26.5%) and acaricide (15.1%). Although herbicides were found in small quantities, yet they were not reported frequently in FA (0.7%) and nFA (1.5%) farms. Adjuvants, fumigants, growth regulators, nematicides and termite control pesticides were infrequent (< 0.5%) amongst both FA and nFA farms.

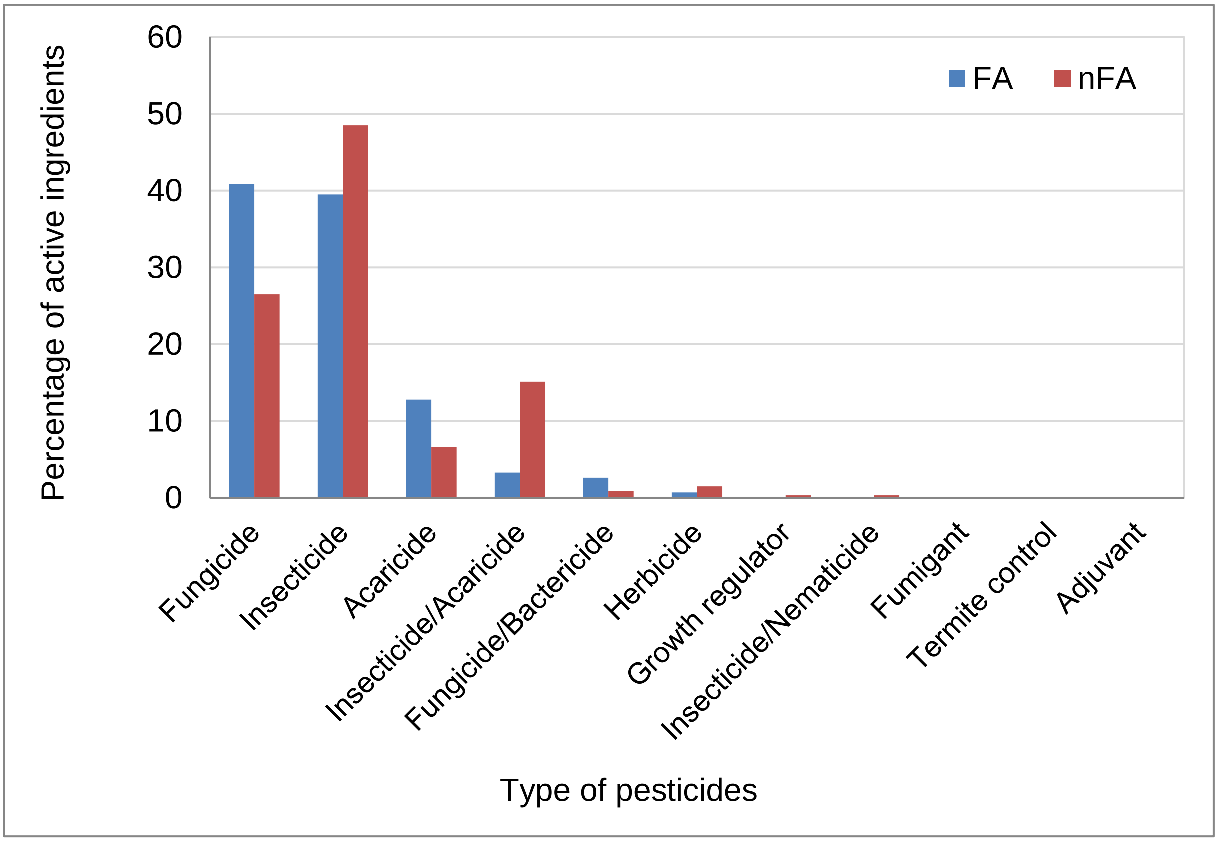


Figure 5.4 Percentage of the total active ingredients found in FA (n=40) and nFA (n=120) farms based on their type of targeted organisms.

5.4.8.4 Pesticide distribution based on “basic producers” and “Me too”

Basic manufacturers are those who identify and registered (patent) the AI. “Me too” pesticides are AIs which are off-patent and so may be produced by many formulators worldwide. Eleven basic manufacturers were identified on the pesticides found in respondents’ farms. The pesticide products of Cheminova were most frequently used on FA (8.3%) and nFA (3.9%) farms followed by Syngenta and DuPont (Table 5.12). Formulated AIs from “Me too” companies were slightly more common on nFA farms (76%) than on FA farms (54%). These pesticides were mainly being imported from China, the Kingdom of Saudi Arabia, Egypt and India and different brand names were often used for the same AI (Photograph 4). However, “Basic products” used by FA farms were doubled (46%) than that used by nFA (24%) ($P < 0.05$, Appendix 33).

Table 5.12 Numbers and percentages of active ingredients found in 160 farms of FA and nFA respondents according to the manufacturers. Generic or "Me too" pesticides are those produced out of patent.

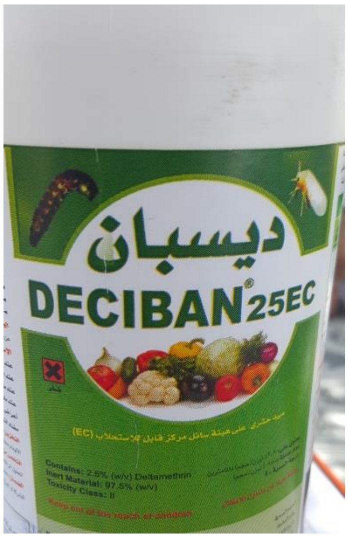
Manufacturer	All Farmers		FA		nFA	
	N	%	N	%	N	%
Me too	615	68	171	54	444	76
Cheminova	49	5.4	26	8.3	23	3.9
Syngenta	48	5.3	25	7.9	23	3.9
Dupont	44	4.9	24	7.6	20	3.4
Bayer cropscience	35	3.9	16	5.1	19	3.2
FMC	34	3.8	15	4.8	19	3.2
Nippon Soda	29	3.2	14	4.4	15	2.6
Mitsui chemicals	24	2.7	5	1.6	19	3.2
Dow agroscience	13	1.4	10	3.2	3	0.5
Sumitomo chemical	6	0.7	6	1.9	0	0
Nihon Noyaku	5	0.6	2	0.6	3	0.5
Agro-Kanesh	1	0.1	1	0.3	0	0

1. Deltamethrin

a)

b)

c)



2. Acetamiprid

d)

e)

f)

Photograph 4. Examples of off-patent or “Me too” pesticides found in FA and nFA farms. There are many brands names (Trade names) for each active ingredient from different sources and they could be produced in different countries. Examples for deltamethrin (a-c) and acetamiprid (d-f) with different brand names but the same content are illustrated.

5.4.8.5 Pesticides present in FA and nFA farms based on country of origin

The pesticides found in FA and nFA farms, were imported from 22 different countries. Most of the active ingredients used in FA and nFA (especially nFA) were from China (13.7% and 27.9%) respectively (Figure 5.5). Switzerland constituted the second source of FA active ingredients (12.8%) while KSA represented the second source of nFA farms (10.6%). Japan ranked as the third source of active ingredients for FA farms (8.4%) in comparison to 5.8% for nFA. A round 7% of FA used products imported from Germany and UK while only 3% of nFA used products manufactured in Germany and 2% in the UK (Figure 5.5).

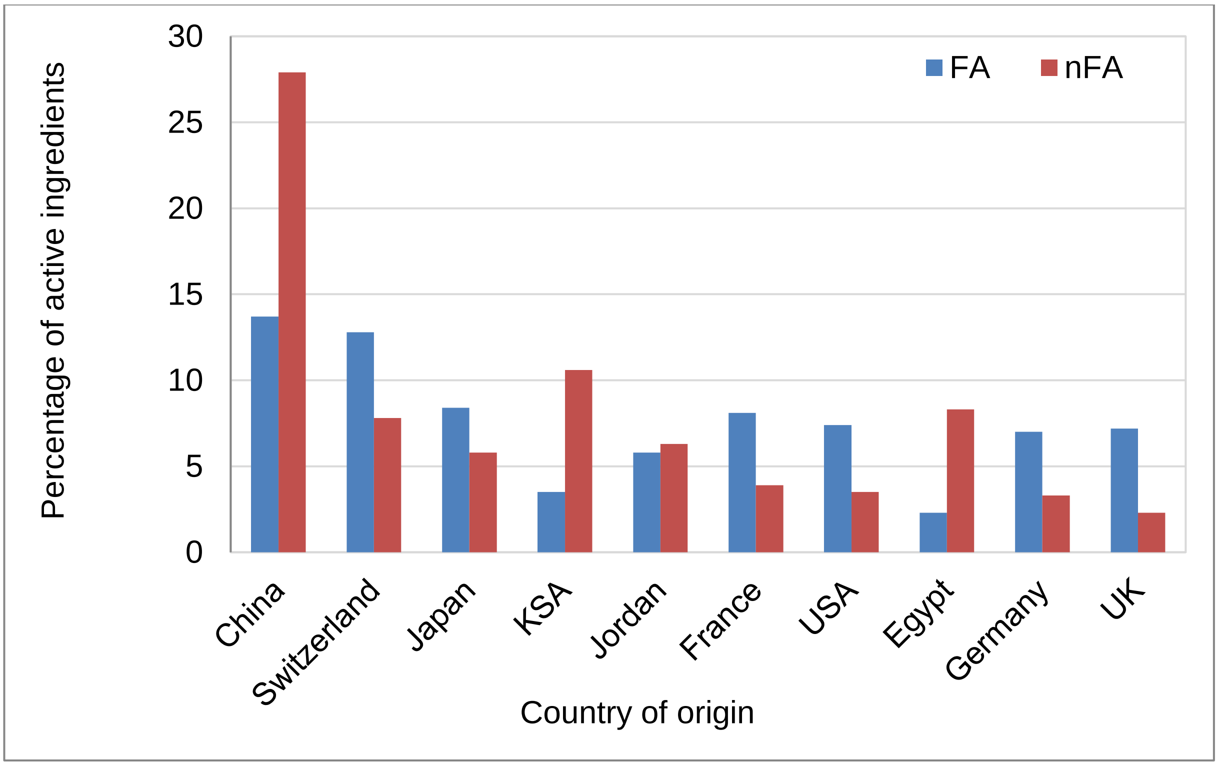


Figure 5.5 Percentage of top 10 used active ingredients in FA (n=40) and nFA (n=120) farms based on their country of origins. (For the rest of AIs sources refer to Appendix 34).

5.5 Discussion and conclusion

5.5.1 Discussion

The objective of this chapter was to examine the awareness amongst farmers on the potential adverse effects of pesticides to human beings and the environment and to investigate the potential factors affecting farmers' perceptions and practices. Incorrect and excessive use of pesticides is very likely to lead to adverse effects on human health (Fieten et al., 2009, Lu, 2009, Xu et al., 2010, Ye et al., 2013, De Jong et al., 2014, Matsukawa et al., 2015, Raanan et al., 2015, Tsimbiri et al., 2015, Zhao, M.A., et al. 2016, Atabila et l., 2017, Riaz et al., 2017, Kongtip et al., 2018, Lehmann et al., 2018, Damalas and Koutroubas, 2018, Lytras et al., 2018, and ocular Memon et al., 2019) and damage the environment (Wang et al., 2007, Zhang et al., 2011, Connoly, 2013, Smalling et al., 2013, Anderson et al., 2015, Anderson et al., 2015, da SILVA et al., 2015, Simon-Delso et al., 2015, Codling et al., 2016, Baron et al., 2017, Codling et al., 2017, Carazo-Rojas et al., 2018, Karahan et al., 2018, Tosi et al., 2018, Bonmatin et al., 2019, Taiwo, 2019, Tosi and Nieh, 2019 and Hesselbach et al., 2020).

Respondents who were members of the FA revealed a better understanding of the potential adverse effects of pesticides than respondents who were not. Alarmingly, the majority of nFA respondents (61%) did not believe that pesticides could cause harmful effects either to people or the environment in contrast to (5%) of FA respondents. These perceptions were affected significantly by status of respondents. Tenants and foremen of FA showed better awareness of pesticides risks in contrast to tenants and foremen of nFA. FA respondents could be supported with information they may obtained from owners who are sharing knowledge with other FA members. Another challenge to awareness of risk is that, as described in Chapter 2, a few FA and many nFA respondents were illiterate and about 13% of FA and 30% of nFA respondents had only acquired a primary level of education. In the present study, the education level gave the FA farmers the predominance in their awareness of the potential risks of pesticides. Lower educational attainment has been found to be a determining factor affecting pesticide applicators' awareness and practices both in Oman (Esechie and Ibitayo, 2011 and Al Zadjali et al., 2015) as well as elsewhere in the world (Salameh et al., 2004, Fan et al., 2015 and Mattah, Futagbi, 2015 and Berni et al., 2021). Moreover, Bagheri et al. (2019) reported that farmers with a good knowledge of the potential of pesticides to cause harm were selecting lower risk pesticides and were using more personal protective equipment. They also concluded that farmers demonstrating better knowledge, attitude, and perceptions could protect themselves against the harmful effects of pesticides. Pesticide experience was associated with a greater awareness among FA farmers on the possible risks of pesticides than for nFA which could be due to a greater accumulation of knowledge over time. Training could improve the awareness of pesticide risks but due to the small number of FA and nFA farmers who had been trained, the effect and difference was unclear. Farmers could obtain information on the risks of pesticides from other members of the FA which may reflect the difference between FA and nFA farmers' perceptions and awareness at A'Suwaiq wilaya and between A'Suwaiq and other Wilayats such as Barka, Al Musanah, Sohar and Shins.

The survey revealed that while more than half of the FA respondents understood the adverse effects of pesticides to soil/water, livestock, wildlife and human health, only 15% of the nFA respondents did. Al Zadjali et al. (2013) similarly found that over 64% of nFA respondents had not thought about such adverse effects. Although Al Zadjali et al. (2013) found that more than 70% of FA owners were aware of the threat of pesticides to the environment, they concluded that there was a weakness in knowledge transfer between farm owners and workers in both FA and non-FA farms. This may help to explain why health and safety measures were a low priority amongst FA and nFA respondents regardless of their status in the farm. However, understanding the potential risks of pesticides to humans and the environment by the owners or tenants of FA and nFA farms does not mean the pesticide applicators will understand such risks. Ignorance of such risks has also been reported and observed elsewhere (Lekei et al., 2014, Damalas and Abdollahzadeh, 2016, Gesesew et al., 2016 and Dhananjayan and Ravichandran, 2018).

Irrespective of other factors, training and continuing professional development targeted at pesticide use might be expected to raise awareness of pesticide applicators to health and safety issues. The study identified, however a serious absence of such training among both FA and nFA respondents. Only 13% of FA and 2.5% of nFA respondents attended any training programmes throughout their farming life despite an average of 14 and 13 years of pesticide experience, respectively. For the non-educated pesticide applicators, training could be a supportive factor that would help applicators reduce exposure risks (Damalas and Koutroubas, 2018 and Berni et al., 2021) and could work as a bridge between knowledge and practice when applying pesticides (Yuantari et al., 2015). The present survey revealed that most of FA and nFA respondents claimed not to have observed any adverse effects of pesticide exposure on themselves. Some, however, did describe occasionally encountering such problems. During the survey, it was also noticed that respondents who encountered health problems due to pesticide application, hesitated to disclose this information to avoid problems with their employer and risk losing their jobs. Hesitation may also have been because some were either illegal immigrants or they could be doing jobs proscribed on their residence permit. A previous survey performed in Al-Batinah region in Northern Oman identified substantial adverse effects of pesticides on applicators (Esechie and Ibitayo, 2011). In this survey, only one pesticide applicator had the courage to disclose an effect which was attributed to pesticide exposure on his hands (Photograph 2). Hence, the difference between FA and nFA respondents in showing adverse effects of pesticides on themselves was not disclosed clearly by the respondents which may account for the absence of any significant difference between the two groups. Nonetheless, poisoning cases admitted to the Accident and Emergency Department in Sultan Qaboos University Hospital in Oman have also reported. There were nine poisoning cases due to rodenticides and one case of insecticide poisoning (Hanssens et al., 2001) but the circumstances of these incidents were not explained by the patients. However, such cases give an indication of some poisoning accidents due to pesticide exposure. Therefore, more investigation is needed to check the potential cases in other hospitals which may reveal the scale of pesticide injuries in Oman.

One reason for the occurrence of adverse effects of pesticides is reluctance towards using PPE. Most pesticide applicators refrained from wearing PPE when they were handling pesticides with around one third of FA and nFA respondents “never” using PPE when applying pesticides. The difference between FA and nFA respondents in using PPE was not significant. However, comparison between owners and workers in Al Batinah region of Northern Oman showed that owners of FA and nFA farms and workers of FA farms were more likely to use PPE (Al Zadjali et al., 2015). However, testing the knowledge of respondents is not the same as what happens in the field when the workers generally carry on the mixing and spraying of pesticides in the absence of the farmland owner. In the present study a particular effort was made to speak to the people responsible for handling pesticides which is highly pertinent since Al Zadjali et al. (2013) found that there was a weakness in knowledge transfer between farm owners and workers in both FA and nFA farms. Thus, owners may know and understand the importance of PPE to protect the pesticide applicators but still there is a lack of implementing such knowledge in the field. The same findings were also reported in Indonesia by Yuantari et al. (2015) who concluded that although the farmers knew the adverse effects of pesticides to humans, yet the farmers did not take any protective measures. However, understanding the factors influencing the farmer’s decision either to use PPE or not, is the key element to mitigate the exposure of applicators to pesticides. Some studies linked willingness to use PPE and usefulness (Sharifzadeh et al.,2017). Another study concluded that farmers who perceived pesticides as harmful substances or those who had an episode of harmful exposure in the past, reported more frequent use of several PPE items (Damalas and Abdollahzadeh, 2016). However, Education level, experience, training, crop features, spraying equipment, nozzle type, operator movement, pesticide formulation and environmental conditions were reported as factors hindering the use of PPE by applicators and hence, increasing the exposure risks (Akter et al., 2018 and Cerruto et al., 2018). Houbraken et al. (2016) found that education, past exposure experience, uncomfortable environmental conditions and the cumbersome equipment made some farmers inclined to ignore the safety measures and increase the risk of pesticide poisoning. In Oman, PPE such as overalls, which are not designed for use under elevated temperatures especially during summer season, could be one of the reasons making pesticides applicators unreceptive to the use of PPE. The same reason was also reported in Taiwan by (Weng and Black, 2015). Nonetheless, elevated temperatures are probably not the main reason but simply that most of the farmers (especially nFA) believed that pesticides were not harmful to humans or the environment. This may explain why more than half of FA and nFA farmers never used any PPE or used their own clothes which was frequently observed during the survey (Photograph 1). It is suggested that an effective way to nudge farmers towards using PPE would be to develop training programmes to farmers to fill the gap between awareness and practice as has also been suggested by Calliera et al. (2013) and Yuantari et al. (2015).

Using PPE is related to safety instructions stated clearly on the pesticide label. In the present study, FA respondents indicated that they read the label safety instructions before using pesticides to a greater extent than the nFA respondents. Reading of safety instructions was also reported in Ethiopia (Mengistie et al., 2017), Kuwait (Jallow et al., 2017), India (Dayanidhi, et al., 2016) and Pakistan (Damalas and Khan, 2016) and many other countries worldwide but it does not mean adherence to these instructions in the field. A further problem is that most of the nFA respondents may not understand Arabic as they were mainly from Bangladesh, Pakistan, India and Afghanistan. Label instructions are, however, written in the Arabic language which is difficult for them to read and understand. Language was also identified as preventing people from reading pesticide labels by Damalas and Khan (2016) and Dugger-Webster and LePrevost (2018). The present study revealed the importance of designing training programmes for non-Arabic speakers in their own languages to increase their awareness about the best ways to handle and use pesticides, to encourage the wearing of PPE and reading the safety instructions on a pesticide's label. Tenants of FA appeared to be more likely to read the safety instructions than tenants of nFA. However, owners, tenants and foremen are supposed to transfer the knowledge of pesticide handling to their workers (pesticide applicators) but these results indicated little involvement of owners (especially nFA) in the pesticide application process as was reported previously by Al Zadjali et al. (2015). Age and pesticide experience and education level all positively affected the likelihood of reading safety instructions. Esechie and Ibitayo (2011) also found that a higher education level improved the safety practices amongst vegetable farmers in Al Batinah.

In general, FA respondents were better at identifying the meaning of safety pictograms than nFA but less than half of the FA respondents understood the pictograms for proper storage and spraying. Other studies have found that pictograms could be vague or confusing (Dugger-Webster and LePrevost, 2018) and instructions to wear PPE are frequently ignored (Abbassy, 2017). Essentially, these problems are symptomatic of weak extenstion services and an urgent need for training.

The lack of training and the general failure of extension services to inform respondents about the banned and restricted pesticides also reveals that there is a missing link between farmers and extension services that needs to be addressed to improve pesticide applicators' understanding of label instructions including pictogram and the implementation of these directions. Fan et al. (2015) also found that ineffective involvement of the government officials was the main cause of increased rates of work-related pesticide poisoning and environmental hazards in China.

The use of abamectin was often reported by both FA and nFA respondents. Abamectin belongs to the micro-organism-derived chemical group but its active ingredient was classified as (Ib) by WHO due to its acute hazards. The pesticide is frequently used since it works as an insecticide/acaricide especially during the summer season when mites are more prevalent and reproduce quickly. Abamectin was also reported by Al Zadjali et al. (2014) as the most frequently used pesticide amongst nFA respondents. Esechie and Ibitayo (2011) reported organophosphates as the most frequently used chemical group in greenhouses in Al Batinah region. In 2012, most of organophosphate pesticides were banned (e.g Dimethoate) or restricted (e.g Cadusafos and Chlorpyrifos). Other chemical group pesticides listed as micro-organism-derived and pyrethroids are still allowed to be used on agricultural crops. Despite their potential health hazards, organophosphates are still in use and farmers prefer to use them due to their effectiveness against the pest and diseases (Lekei et al., 2014). In this study, two banned pesticides (Dimethoate and 2,4-D) were observed on nFA farms. Moreover, around seven restricted pesticides were also reported to be used within nFA farms including Cadusafos, Chlorpyrifos, Cypermethrin, Imidacloprid, Lambda-cyhalothrin, Methomyl and Methyl-bromide. Only two of the restricted pesticides (Lambda-cyhalothrin and Methomyl) were found on FA farms. In the past, some of the banned and restricted pesticides were also reported in nFA farms (Thacker et al., 2000 and Al Zadjali et al., 2014). The banned pesticides are not available in the local market in Oman, but are smuggled from neighbouring countries especially the UAE where banned pesticides like Dimethoate were allowed before the pesticide regulations were unified within GCC countries (Photograph 3). Some of the farmers (especially nFA) still feel that banned pesticides are more efficient than new formulations.

Farmer association respondents were using substantially less insecticide and more fungicide than nFA respondents. However, almost all of the FA respondents grow tomatoes and during the survey period, early and late blight diseases were widespread on tomatoes in Oman which forced FA respondents to use many and high quantities of fungicides to tackle the problem. In addition, the frequent use of the same pesticide over several seasons may evolve resistance. The problem is exacerbated with overuse of pesticides and the low quality of cheapest products.

The present study showed that the majority of pesticides used were generic or “me too”. In FA farms, “me too” pesticides constituted 54% while in nFA farms they were 76%. Products produced by the original patent holding companies were more frequently used in FA than in nFA farms. The price of “Me too” pesticides is also much lower than the products from the main pesticide producers such as Bayer, Syngenta, DuPont and Sumitomo. In addition to pesticide prices, high prices of agricultural inputs such as seeds, fertilizers, low market prices of fruits and availability of these products without any restrictions or judicious direction of use may force farmers to buy the cheapest formulated pesticides (Photograph 4). The majority of the cheaper “Me too’ pesticides are imported from China, with some being manufactured in the Kingdom of Saudi Arabia, Egypt and India; they are lower in quality and less effective (Durmusoglu et al., 2008 and Al Zadjali et al., 2014).

5.5.2 Conclusion

The hypothesis of this chapter is: The FA members are more aware than nFA members of the health and safety measures required when handling pesticides.

The objective of this chapter was to assess the knowledge, perceptions and practices of FA and nFA respondents in regard to health and safety measures when handling, mixing and spraying pesticides. The study revealed that FA respondents, to some extent, better understood the adverse impacts of pesticides on humans and the environment than nFA respondents. Nevertheless, few used PPE when mixing or spraying pesticides. Status, age, education level, experience and training are factors that could enhance the awareness, perceptions and practices of the respondents or pesticide applicators towards the safety measures needed when using pesticides. Limitations that could hinder respondents from adhering to the health and safety measures include weak extension services, lack of training programmes, low education level, absence of strict regulations and their enforcement, lack of collaborations between stakeholders and the absence of an association for nFA respondents. A lack of knowledge, poor communications from MAFWR, and unenforced regulations were the main reasons causing the farmers to ignore the health and safety measures they ought to follow to minimize the risk of pesticides to humans and the environment.

Based on the findings, the null hypothesis was rejected.

5.6 Recommendations

1. Designing and implementing national training programs to increase awareness of pesticide applicators, extension officers, retailers, farmers and the public of how to use pesticides more safely.

2. Gathering and involving the pesticide applicators in workshops to discuss health and safety measures and to allow them to disclose their perceptions on the risks associated with pesticide use in vegetable crops.

3. Encouraging farmers or pesticide applicators to use evaluate non-chemical measures of pest and disease control to reduce the risk of exposure to humans and environment to unsafe levels of pesticides.

4. Reinforcing the regulations which obligate the farm owners or tenants to provide PPE to the pesticide applicators and observe the implementation of the law and other regulations to protect the pesticide applicators. The other recommendation is to insist retailers provide PPE to farmers at cost price or for the government to provide it at a subsidised price and then to monitor their adherence in using it.

5. Analysing imported pesticides for quality to ensure they adhere to the specifications to reduce the number of treatments per season and consequently reduce the exposure to pesticides.

6. Increase the surveillance and monitoring of pesticide applications and residues in the farms to make sure pesticide users adhere to the laws relating to pesticide use and residues acceptable limits.

7. Register and study the cases of pesticide poisoning that are admitted to hospitals and investigate the reasons and discuss the methods to reduce and stop similar cases.

5.7 References

Abbassy, M. M. S. (2017) ‘Farmer’s knowledge, attitudes and practices, and their exposure to pesticide residues after application on the vegetable and fruit crops. case study: North of delta, Egypt’, *Journal of Environmental & Analytical Toxicology*, 7, 5.

Akter, M., Fan, L., Rahman, M. M., Geissen, V. and Ritsema, C. J. (2018) ‘Vegetable farmers’ behaviour and knowledge related to pesticide use and related health problems: A case study from Bangladesh’, *Journal of Cleaner Production*, 200, pp. 122-133.

Al Zadjali, S., Morse, S., Chenoweth, J. and Deadman, M. (2013) ‘Disposal of pesticide waste from agricultural production in the Al-Batinah region of Northern Oman’, *Science of the Total Environment*, 463-464, pp. 237-242.

Al Zadjali, S., Morse, S., Chenoweth, J. and Deadman, M. (2014) ‘Factors determining pesticide use practices by farmers in the Sultanate of Oman’, *Science of the Total Environment*, 476-477, pp. 505-512.

Al Zadjali, S., Morse, S., Chenoweth, J. and Deadman, M. (2015) ‘Personal safety issues related to the use of pesticides in agricultural production in the Al-Batinah region of Northern Oman’, *Science of the Total Environment*, 502, pp. 457-461.

Anderson, J. C., Dubetz, C. and Palace, V. P. (2015) ‘Science of the total environment neonicotinoids in the Canadian aquatic environment: A literature review on current use products with a focus on fate, exposure, and biological effects’, *Science of the Total Environment,* 505, pp. 409-422.

Atabila, A., Phung, D. T., Hogarh, J. N., Osei-Fosu, P., Sadler, R., Des, C. and Chu, C. (2017) ‘Dermal exposure of applicators to chlorpyrifos on rice farms in Ghana’, *Chemosphere*, 178, pp. 350-358.

Bagheri, A., Emami, N. and Damalas, C. A. (2021) 'Farmers' behavior towards safe pesticide handling: An analysis with the theory of planned behavior', *Science of Total Environment*, 751, (2021) 141709.

Bagheri, A., Emami, N., Damalas, C. A., Allahyari, M. S. (2019) ‘Farmers’ knowledge, attitudes, and perceptions of pesticide use in apple farms of northern Iran: Impact on safety behavior’, *Environmental Science and Pollution Research*, 26, pp. 9343-9351.

Baron, G. L., Jansen, V. A., Brown, M. J., Raine, N. E. (2017) 'Pesticide reduces bumblebee colony initiation and increases probability of population extinction', *Nature Ecology Evolution*, 1, pp. 1308-1316.

Berni, I., Menouni, A., Ghazi El, I., Duca, R-C, Kestemont, M-P, Godderis, L. and El Jaafari S. (2021) 'Understanding farmers' safety behavior regarding pesticide use in Morocco', *Sustainable Production and Consumption*, 25, pp. 471-483.

Bhandari, G., Atreya, K., Yang, X., Fane, L. and Geissena, V. (2018) ‘Factors affecting pesticide safety behaviour: The perceptions of Nepalese farmers and retailers’, *Science of the Total Environment*, 631–632, pp. 1560-1571.

Bonmatin, J., Noome, D. A., Moreno, H., Mitchell, E. A. D., Glauser, G., Soumana, O. S., van Lexmond, M. B. and Sanchez-Bayo, F. (2019) ‘A survey and risk assessment of neonicotinoids in water, soil and sediments of Belize’, *Environmental Pollution*, 249, pp. 949-958.

Calliera, M., Berta, F., Galassi, T., Mazzini, F., Rossi, R., Bassi, R., et al. (2013) 'Enhance knowledge on sustainable use of plant protection products within the framework of the sustainable use directive', *Pest Management Science,* 69, pp. 883-888.

Carazo-Rojas, E. et al. (2018) ‘Pesticide monitoring and ecotoxicological risk assessment in surface water bodies and sediments of a tropical agro-ecosystem’, *Environmental Pollution*, 241, pp. 800-809.

Cerruto, E., Manetto, G., Santoro, F. and Pascuzzi, S. (2018) ‘Operator dermal exposure to pesticides in tomato and strawberry greenhouses from hand-held sprayers’, *Sustainability*, 10, pp. 1-21.

Codling, G., Al Naggar, Y., John P. Giesy, J. P. and Robertson, A. J. (2016) ‘Concentrations of neonicotinoid insecticides in honey, pollen and honey bees (*Apis mellifera* L.) in central Saskatchewan, Canada’, *Chemosphere*, 144, pp. 2321-2328.

Codling, G., Al Naggar, Y., John P. Giesy, J. P. and Robertson, A. J. (2018) ‘Neonicotinoid insecticides in pollen, honey and adult bees in colonies of the european honey bee (*Apis mellifera* L.) in Egypt’, *Ecotoxicology*, 27, pp. 122-131.

Connolly, C. N. (2013) 'The risk of insecticides to pollinating insects', *Communicative integrative biology*, 6, 1634.

Damalas, C. A. and Abdollahzadeh, G. (2016) ‘Farmers’ use of personal protective equipment during handling of plant protection products: Determinants of implementation’, *Science of the Total Environment*, 571, pp. 730-736.

Damalas, C. A. and Khan, M. (2016) ‘Farmers’ attitudes towards pesticide labels: Implications for personal and environmental safety’, *International Journal of Pest Management*, 62, pp. 319-325.

Damalas, C. A. and Koutroubas, S. D. (2016) ‘Farmers’ exposure to pesticides: Toxicity types and ways of prevention’, *Toxics*, 4, pp. 1-10.

Damalas, C. A. and Koutroubas, S. D. (2018) ‘Farmers’ behaviour in pesticide use: A key concept for improving environmental safety’, *Current Opinion in Environmental Science and Health*, 4, pp. 27-30.

Da Silva, I. P., Oliveira, F. A. S., Gadelha, H. P. P., Melo, M. M. and Soto-Blanco, B. (2015) 'Pesticide exposure of honeybees (*Apis mellifera*) pollinating melon crops', *Apidologie*, 46, pp. 703-715.

De Jong, K., Boezen, H. M., Kromhout, H., Vermeulen, R., Postma, D. S. and Vonk, J. M. (2014) 'Association of occupational pesticide exposure with accelerated longitudinal decline in lung function', *American Journal of Epidemiology*, 179, pp. 1323-1330.

Dhananjayan, V. and Ravichandran, B. (2018) 'Occupational health risk of farmers exposed to pesticides in agricultural activities', *Current Opinion in Environmental Science and Health*, 4, pp. 31-37.

Dugger-Webster, A. and LePrevost, C. E. (2018) 'Following pesticide labels: A continued journey toward user comprehension and safe use', *Current Opinion in Environmental Science and Health*, 4, pp. 19-26.

Durmusoglu, E., Madanlar, N. and Weintraub, P. G. (2008) 'Active ingredient contents of "me-too" registered abamectin products and differences in their efficacy on *Tetranychus cinnabarinus*', *Phytoparasitica*, 36, pp. 231-241.

Esechie, J. O. and Ibitayo, O. O. (2011) 'Pesticide use and related health problems among greenhouse workers in Batinah Coastal Region of Oman', *Journal of Forensic and Legal Medicine*, 18, pp. 198-203.

Fan, L., Niu, H., Yang, X., Qin, W., Bento, C. P. M., Ritsema, C. J. and Geissen, V. (2015) 'Factors affecting farmers' behaviour in pesticide use: Insights from a field study in northern China', *Science of the Total Environment*, 537, pp. 360-368.

Food and Agricuture Organisation (2018) '*Pesticide statistics'*, *FAO annual report, 2018*.

Fieten, K. B., Kromhout, H., Heederik, D. and Wendel de Joode, B van. (2009) 'Pesticide exposure and respiratory health of indigenous women in Costa Rica', *American Journal of Epidemiology*, 169, pp. 1500-1506.

Gesesew, H. A., Woldemichael, K., Massa, D. and Mwanri, L. (2016) 'Farmers knowledge, attitudes, practices and health problems associated with pesticide use in rural irrigation villages, Southwest Ethiopia', 11, pp. 1-13.

Hanssens, Y., Deleu, D. and Taqi, A. (2001) 'Etiologic and demographic characteristics of poisoning: A prospective hospital-based study in Oman', *Journal of Toxicology - Clinical Toxicology*, 39, pp. 371-380.

Hesselbach, H., Seeger, J., Schilcher, F., Ankenbrand, M. and Scheiner, R. (2020) 'Chronic exposure to the pesticide flupyradifurone can lead to premature onset of foraging in honeybees *Apis mellifera*', *Journal of Applied Ecology*, 57, pp. 609-618.

Houbraken, M., Bauweraerts, I., Feverya, D., Labeke, M. V., and Spanoghe, P. (2016) ‘Pesticide knowledge and practice among horticultural workers in the Lâm Dông region, Vietnam: A case study of chrysanthemum and strawberries’, *Science of the Total Environment*, 550, pp. 1001-1009.

National Centre for Statistics (2020) '*Statistics'*, https://www.*ncsi.gov.om/Pages/NCSI.aspx*.(Access on 20 March 2021).

Jallow, M. F. A., Awadh,D. G., Albaho, M. S., Devi, V. Y and Thomas, B. M. (2017) ‘Pesticide knowledge and safety practices among farm workers in Kuwait: Results of a survey’, *International Journal of Environmental Research and Public Health*, 14, pp. 1-15.

Karahan, A., Kutlu, M. A. and Karaca, İ. (2018) ‘Determination of the effect of some pesticides on honey bees’, *International Journal of Agriculture, Environment and Food Sciences*, 2, pp. 104-108.

Kim, K. H., Kabir, E. and Jahan, S. A. (2017) ‘Exposure to pesticides and the associated human health effects’, *Science of the Total Environment*, 575, pp. 525-535.

Kongtip, P., Noppanun Nankongnab, N., Mahaboonpeeti, R., Bootsikeaw, S., Batsungnoen, K, Hanchenlaksh, C., Tipayamongkholgul, M. and Woskie, S. (2018) ‘Differences among Thai agricultural workers’ health, working conditions, and pesticide use by farm type’, *Annals of Work Exposures and Health*, 62, pp. 167-181.

Lehmann, E., Oltramarea, C., Dibiéb, J. N., Konatéb, Y. and de Alencastro, L. F. (2018) ‘Assessment of human exposure to pesticides by hair analysis: The case of vegetable-producing areas in Burkina Faso’, *Environment International*., 111, pp. 317-331.

Lekei, E. E., Ngowi, A. V. and London, L. (2014) ‘Farmers’ knowledge, practices and injuries associated with pesticide exposure in rural farming villages in Tanzania’, *BMC Public Health*, 14, pp. 1-13.

Lu, J. L. (2009) ‘Total pesticide exposure calculation among vegetable farmers in Benguet, Philippines’, *Journal of Environmental and Public Health*, 2009, pp. 1-5.

Lytras, T. *et al.* (2018) ‘Occupational exposures and 20-year incidence of COPD: The european community respiratory health survey’, *Thorax, 73*, pp. 1008-1015.

Matsukawa, T., Yokoyama, K. and Itoh, H. (2015) ‘Ocular irritation from product of pesticide degradation among workers in a seed warehouse’, *Industrial Health*, 53, pp. 95-99.

Mattah, M. M., Mattah, P. A. D. and Futagbi, G. (2015) ‘Pesticide application among farmers in the catchment of ashaiman irrigation scheme of Ghana: Health implications’, *Journal of Environmental and Public Health*, 2015, pp. 1-7.

Memon, Q. Ul. A., Wagan, S. A., Chunyu, D., Shuangxi, X., Jingdong, I. and Damalas, C. A. (2019) ‘Health problems from pesticide exposure and personal protective measures among women cotton workers in southern Pakistan’, *Science of the Total Environment*, 685, pp. 659-666.

Mengistie, B. T., Mol, A. P. J. and Oosterveer, P. (2017) ‘Pesticide use practices among smallholder vegetable farmers in Ethiopian Central Rift Valley’, *Environment, Development and Sustainability*, 19, pp. 301-324.

Mubushar, M., Aldosari, F. O., Baig, M. B., Alotaibi, B. M., Khan, A. (2019) 'Assessment of farmers on their knowledge regarding pesticide usage and biosafety’, *Saudi Journal of Biological Sciences*, 26, pp. 1903-1910.

Okonya, J. S. and Kroschel, J. (2015) ‘A Cross-Sectional study of pesticide use and knowledge of smallholder potato farmers in Uganda’, *BioMed Research International*, 2015, pp. 1-9.

Raanan, R., Harley, K. G., Balmes, J. R., Bradman, A., Lipsett, M. and Eskenazi, B. (2015) ‘Early-life exposure to organophosphate pesticides and pediatric respiratory symptoms in the CHAMACOS cohort’, *Environmental Health Perspectives*, 123, pp. 179-185.

Riaz, S., Manzoor, F., Mahmood, N. and Shahid, S. (2017) ‘Molecular detection of M. tuberculosis and M. bovis and hematological and biochemical analyses in agricultural sprayers exposed to pesticides: A cross-sectional study in Punjab, Pakistan during 2014-2016’, *Journal of Exposure Science and Environmental Epidemiology*, 27, pp. 434-443.

Rijal, J. P., Regmi, R., Ghimire, R., Puri, K. D., Gyawaly, S. and Poudel, S. (2018) ‘Farmers’ knowledge on pesticide safety and pest management practices: A case study of vegetable growers in Chitwan, Nepal’, *Agriculture*, 8, 16.

Rincón, V. J., Páez, F. C. and Sánchez-Hermosilla, J. (2018) ‘Potential dermal exposure to operators applying pesticide on greenhouse crops using low-cost equipment’, *Science of the Total Environment*, 630, pp. 1181-1187.

Salameh, P. R., Baldi, I., Brochard, P. and Abi Saleh, B. (2004) ‘Pesticides in Lebanon: A knowledge, attitude, and practice study’, *Environmental Research*, 94, pp. 1-6.

Sharifzadeh, M. S., Damalas, C. A. and Abdollahzadeh, G. (2017) ‘Perceived usefulness of personal protective equipment in pesticide use predicts farmers’ willingness to use it’, *Science of the Total Environment*, 609, pp. 517-523.

Simon-Delso, N. *et al.* (2015) ‘Systemic insecticides (Neonicotinoids and fipronil): Trends, uses, mode of action and metabolites’, *Environmental Science and Pollution Research*, 22, pp. 5-34.

Smalling, K. L. *et al.* (2013) ‘Environmental fate of fungicides and other current-use pesticides in a central California estuary’, *Marine Pollution Bulletin*, 73, pp. 144-153.

Stadlinger, N. *et al.* (2011) ‘Pesticide use among smallholder rice farmers in Tanzania’, *Environment, Development and Sustainability*, 13, pp. 641-656.

Taiwo, A. M. (2019) ‘A review of environmental and health effects of organochlorine pesticide residues in Africa’, *Chemosphere*, 220, pp. 1126-1140.

Thacker J. R. M, Q. Ambusaidi, M. Al-Azri, R. Al-Fahdi, K. AL-Hashmi, R. Al -Jabri, S. Al-Makhmari, I. Al-Mandheri, A. A.-S. and R. A.-S. (2000) ‘Assessment of pesticides use on farms in Al Batinah, Oman. *Agricultural Sciences*, 5, pp. 79-84.

Tosi, S., Costa, C., Vesco, U., Quaglia, G. and Guido, G. (2018) ‘A 3-year survey of Italian honey bee-collected pollen reveals widespread contamination by agricultural pesticides’, *Science of the Total Environment*, 615, pp. 208-218.

Tosi, S. and Nieh, J. C. (2019) ‘Lethal and sublethal synergistic effects of a new systemic pesticide, flupyradifurone (Sivantow), on honeybees’, *Proceedings of the Royal Society B: Biological Sciences*, 286(1900).

Tsimbiri, P. F., Moturi, W. N., Sawe, J., Henley, P. and Bend, J. R. (2015) ‘Health impact of pesticides on residents and horticultural workers in the lake naivasha region, Kenya’, *Occupational Diseases and Environmental Medicine*, 3, pp. 24-34.

Dayanidhi, V. K., Hedge, S. P., Chendrashekaran, P. and Begum, K.. (2016) ‘A Cross-Sectional survey on the awareness of pesticide labels and pesticide safety pictograms among paddy farming In South India’, *Journal of Health Sciences and Surveillance System*, 4, pp. 158-166.

Wang, Y., Kruzik, P., Helsberg, A., Helsberg, I. and Rausch, W. (2007) ‘Pesticide poisoning in domestic animals and livestock in Austria: A 6 years retrospective study’, *Forensic Science International*, 169, pp. 157-160.

Weng, C. Y. and Black, C. (2015) ‘Taiwanese farm workers pesticide knowledge, attitudes, behaviors and clothing practices’, *International Journal of Environmental Health Research*, 25, pp. 685-696.

World Health Organisation. (2009) 'The WHO recommended clasification of pesticides by hazard and Guidelines to Classification',Online at: https://apps.who.int/iris/bitstream/handle/10665/44271/9789241547963_eng.pdf?sequence=1&isAllowed=y (Access on July 2021).

Xu, X., Dailey, A, B., Talbott, E. O., Ilacqua, V. A., Greg Kearney, G. and Asal, N. R. (2010) ‘Associations of serum concentrations of organochlorine pesticides with breast cancer and prostate cancer in U.S. adults’, *Environmental Health Perspectives*, 118, pp. 60-66.

Ye, M., Beach, J., Martin, J. W. and Senthilselvan, A. (2013) ‘Occupational pesticide exposures and respiratory health’, *International Journal of Environmental Research and Public Health*, 10, pp. 6442-6471.

Yuantari, M. G. C., Van Gestel, C. A. M., Van Straalen, N. M., Widianarko, B., Sunoko, H. R. S. and Shobib, M. N. (2015) 'Knowledge, attitude, and practice of Indonesian farmers regarding the use of personal protective equipment against pesticide exposure', *Environmental Monitoring and Assessment*, 187, 142.

Zhang, W., Jiang, F. and Ou, J. (2011) 'Global pesticide consumption and pollution: With China as a focus', 1, pp. 125-144.

Zhao, M., Yu, A., Zhu, Y., Wu, S. and Kim, J. (2016) 'Human exposure and risk assessment of chromafenozide during treatment in rice fields', *Human and Ecological Risk Assessment*: *An International Journal,* 22, pp. 116-125.

Chapter 6. Assessment of pesticide retailers' ability to identify pests and diseases, proper pesticide selection and application and their perceptions on pesticide health and safety measures.

6.1 Summary

The objective of this study is to investigate the pesticide retailers' perceptions and knowledge regarding pests and diseases diagnosis, proper pesticide selection and application and health and safety measures. A survey of 75 pesticides retailers was conducted in seven different districts in the northern parts of the Sultanate of Oman. Most of the respondents were able to identify the major vegetable crop pests and diseases such as spodopteran and whitefly (>90%). Nonetheless, only a few respondents (12%) were able to identify thrips correctly. It is noteworthy that, education level, training and nationality of respondents were associated with their ability to identify the problems. More than half of the retailers were able to recommend appropriate pesticides for specific crop protection problems but as many as 45% were unable to identify the proper pesticides correctly. Training and nationality significantly affected the retailers' proper selection of pesticides. Inability to identify the problems led to the respondents' improper pesticide selection (82%). On dose rates, 34% of the retailers suggested correct dose rates but 66% suggested dose rates below or above the rates recommended on the local labels. Most of the retailers (88%) advised a PHI according to the label recommendation or greater, but 22% suggested shorter PHIs. Only 52% appeared to be aware of the potential risks of pesticides to humans and the environment. Although 97% did not use any protective measures when dealing with pesticides, the same percentage claimed not to have experienced or seen any adverse effects. Less than half (46.6%) of the retailers revealed that they "never" or "rarely" read the label's safety instructions while only 34.7% "usually" and "always did. Their decisions were affected by education level and training programme. Many retailers (>80%) could identify most of the pictogram safety symbols on pesticide labels except for proper spray and proper storage (<40%). The study revealed the need to introduce thorough training programmes for pesticide retailers and concerned government extension officials pertaining to crop protection and pesticide application.

Keywords: pests and diseases, pesticides, dose rate, pre-harvest interval, health and safety

6.2 Introduction

The extent to which pesticide retailers are involved in helping farmer identify pests and diseases, select pesticides, choose application rates advise on health and safety measures for pesticide usage and handling, is not clear. However, there are many reports that show the importance of retailers' contributions to farmers' decision making regarding many agricultural practices, which elucidates the increase in the number of retailers in some parts of the world. According to Panuwet et al. (2012), there were more than 26,000 retailers available in Thailand licensed to sell more than 20,000 pesticide formulations. In Vietnam, the number of licensed retailers exceeded 27,000 by 2009. In such cases, the enforcement of pesticide rules and regulations becomes difficult due to the large numbers of licensed and unlicensed retailers (Hoi et al., 2009). Sometimes the governmental practices increased the number of retailers as happened in Tanzania when the government removed the farmers' subsidies during the 1990s. The number of licensed pesticide retailers increased from 2 in 1988 to 160 in 1997 (Stadlinger et al., 2013). Despite the high numbers of retailers in many countries, their role in providing advice on pesticides is not taken into consideration sufficiently. In China, a study, conducted by Haj-Younes et al. (2015), reported that despite the fact that retailers seemed to play a role as an information source to pesticide users, they remain a poorly-studied group in academic literature. Nonetheless, a study of 209 farmers and 20 retailers in two regions of China (Qianyang and Chencang) revealed that all retailers provided information to farmers on the use of pesticides while selling them the products (Yang et al., 2014). Retailers seemed to act as a channel between pesticide importers/wholesalers and end-users such as farmers. The role of retailers depends on the government official services in the rural areas (Hoi et al., 2013). If the extension services are strong and efficient, they are considered a trusted source of information to farmers. When there is an absence of effective governmental scheme or body to manage pesticide handling, retailers normally occupy the gap and become the main source of information to end users (Panuwet et al., 2012, Stadlinger et al., 2013 and Fan et al., 2015). However, farmers/end users obtain information on pests and diseases identification (Schreinemachers et al., 2017), pesticide selection and application (Zhang and Lu, 2007, Weng and Black, 2015, Ali et al., 2020, Jin et al., 2015, Fan et al., 2015, Haj-Younes et al., 2015 and Huang, 2021) and health and safety measures of pesticide (Kesavachandran et al., 2009, Lekei et al., 2014 Schreinemachers et al., 2015, Damalas and Khan, 2016, Bhandari et al., 2018, Neghab et al., 2018, Mubushar et al. 2019) from retailers.

In Oman, retailers also play major roles in crop protection issues including pest and disease diagnosis and pesticide selection and application. In the absence of qualified or effective government extension services (Al Zadjali et al., 2014), farmers depend on retailers for advice on many aspects of pesticide use. According to Al Zadjali et al. (2014), owners of farms that are included within the FA are more directly involved in decision-making with respect to pesticide applications while nFA personnel indicated that none of the farm owners was a source of advice, and instead pesticide sellers and friends were used as reference sources, along with the workers' own personal experience. The farm-based survey (Chapter 2) of this thesis which targeted FA and nFA farmers showed that about 68% of FA respondents and 77% of nFA respondents got help in diagnosis of different pests and diseases from retailers and 63% of FA and 87% of nFA respondents selected pesticides following a retailer’s advice. Dependence of many farmers on retailers’ recommendations of certain active ingredients, which may be incorrect, could exacerbate the pesticide application dilemma. Nonetheless, these results indicate the importance of retailers as a key source of advice on pesticides in the country and they also show the need to investigate the perceptions, knowledge and factors affecting the quality of retailers’ advice such as education, age, experience, training, location, status, nationality and years of operation as retailers to understand the whole picture of pest and disease identification, pesticide selection and application and health and safety aspects of using pesticides in Oman. The actual number of pesticide retailers in Oman is not known and the accurate or definite roles of retailers in crop protection issues have not been investigated previously. The hypothesis of this chapter is that there is no difference between retailers in their ability to diagnose pests and diseases, decide on pesticide selection and applications and recognise the adverse effects of pesticides on human and environment. However, a detailed study of retailer’s knowledge, perceptions and attitudes towards directing end users such as farmers becomes imperative. The aim of this Chapter is to investigate the pesticide retailers’ perceptions and knowledge of pest and disease diagnosis, proper pesticide selection and application and health and safety measures in relation to farmers’ attitudes towards these practices. The study also tried to identify the cognitive factors that may drive retailers' perceptions and knowledge towards the advice they offer to farmers for diagnosis, pesticide selection and application and health and safety issues. In addition, the study aimed to answer the research question:

> Can pesticide retailers diagnose the common pests and diseases of the vegetable crops, select the proper pesticides and recommend the proper application rates and PHI and are they aware of the potential risks associated with pesticides?

6.3 Materials and Methods

6.3.1 Introduction

This section describes the methodology designed and used to address the objectives of the study. It includes quantitative data collection using a structured questionnaire with open-ended and closed questions (Appendix 35). The 44 questions investigated different aspects to characterise the company and respondent, work experience, pest and disease identification and health and safety awareness and precautions. Some of the questions were intentionally identical to those in the farmers' survey to facilitate comparisons with the farmers. However, to accommodate variation, other sections of the questionnaire diverged for farmers and retailers (full details are in Chapters 2, 3, 4 and 5). As described in Chapters two and three with farmers, approaching retailers through post or the internet was very difficult. Consequently, the questionnaire was administered on a face-to-face interview basis. Prior to the deployment of the retailers' questionnaire, a pilot study was conducted to test the robustness of the questions.

5.3.2 Retailers' survey - Pilot study

The feasibility of the retailer questionnaire was assessed to ensure the applicability of the questions to the requirements of the main objectives of the research and to ensure the appropriateness of the type and design of the questions to the overall research project. Two retailers were selected from outside the research sample and their consent was obtained to participate as respondents to highlight the products being sold and their activities in dealing with farmers directly giving advice and support on pesticide selection and use. The structured questionnaire was developed using open-ended and closed questions, demographic information collection, image recognition and Likert scale questions.

The pilot study was conducted during February 2017. Before each interview, retailers were briefed about the purpose of the study and their consent was obtained. Based on the results of the pilot study, many questions were modified. Some changes were made in order to make questions clearer, more direct and more comprehensible. These changes also gave a better structure and validity to the questionnaire since the questions were comprehensive and covered the important issues related to the research objectives. Questions about shop registration with MAFWR and age were excluded because it was felt that the other responses might be compromised if the respondents thought there could be any vulnerability to prosecution. Because several pesticide products were available for some of the insect and disease problems, more space was added for each problem in order to cover all the alternatives. This was considered important since it could provide information on the likelihood of retailers providing different pesticide alternatives to farmers for different problems that a farmer might face during the season, especially pesticide resistance and incorrect problem identification. A question asking, 'Have you ever sold a pesticide that does not work?' was felt accusatory in tone and so was modified to 'What is the percentage of customers buying pesticides solely based on your suggestions?' At the same time, it was important to understand the mechanism of pesticide selection from the other side of the process and so a further question was added as 'What is the percentage of customers buying pesticides solely based on their own understanding?'. As the study aimed to ascertain the possible risk of developing resistance based on proper selection and application of pesticides, three questions were added to the last draft of the questionnaire in order to investigate the potential for that resistance, based on retailer's own experience. Thus, the question 'If farmer bought a pesticide from you and comes back and says that it no longer seems to be as effective as it used to be and the farmer or you suspect there might be pesticide resistance, what would you do/advise?' was added. A second question asked the retailer if s/he was aware of any pesticide resistance problems in their area.

6.3.3 Retailers' survey methodology

Following the pilot study, the questionnaire comprised five sections: general information, retailer and respondent information, retailer's work experience, pesticide risks, and health and safety. The pest and disease diagnosis part of the survey aimed to test the ability of retailers to identify, from photos, common pests and diseases of vegetables in Oman. It also tested their ability to connect diagnosis with a correct active ingredient and application method for each problem. The insect and disease images used for the farm-based surveys were employed to allow a direct comparison of the retailers with both FA and nFA farmers. The risk, health and safety section tested the respondents' knowledge on the safe use of pesticides. Respondents were also questioned on health and safety aspects of pesticide use including: reading the label safety instructions, identification of label safety symbols and the use of personal protective equipment (PPE).

The survey was carried out during the period from March to July 2017 and covered seventy-five pesticide retailers located in the same six governorates as the farmers in Chapter 3 (Figure 3.1). Face-to-face interviews were held on the retailer's premises. Prior to every interview, the researcher explained the purposes of the interview and sought the consent of the retailer to participate in the survey. An explanatory document, including the researcher's name, the survey objectives and contact details was given to each retailer before commencing the interview in order to assure anonymity and guarantee their right to withdraw from the survey at any stage. Each interview lasted between 30 and 60 minutes and was conducted in Arabic and/or English depending on the participant's background.

6.3.4 Statistical analysis

Mean ranks for non-parametric data from the survey questionnaire, including Likert scale questions, were compared using either the Mann-Whitney U-test (for two groups) (Bergmann and Ludbrook, 2000) or Kruskal-Wallis analysis (for more than two groups) (Lyman Ott, 1993). Within Kruskal-Wallis analyses, where significant differences in mean rank were indicated ($P < 0.05$), individual mean ranks were separated using the z-value for significance threshold (Gwet, 2011) implemented within Microsoft Excel. In all analyses $P < 0.05$ was taken to indicate significance in differences between mean ranks or a significant correlation between variables.

6.4 Results

6.4.1 Firms and respondents

6.4.1.1 Demography of respondents (location, status, years of trading, education level and certification).

Vegetable production thrives in Al Batinah south and north governates in Oman which reflects the large number of pesticide retailers from these two regions (64%) in the survey (Table 6.1). Out of seventy-five retailers who participated in this survey, around 80% of them were sellers and 16% were owners indicating that owners are not involved very much in pesticides selling process. Pesticides sellers are the main type of respondent dealing with customers (e.g. pesticides buyers) such as farmers, pest control companies, pesticide applicators and others (Table 6.1). The number of years of a firm's operation in pesticide selling may reflect the years of experience in the business. Around one third of the respondents had been running their pesticide selling business for less than five years (32%). Respondents who had an experience of five to ten years represented 16% while 14% of the respondents operated the business for ten to fifteen years. Out of seventy-five respondents, twelve had sold pesticides for the last fifteen to twenty years (Table 6.1). Respondents showed good education levels, 51% having finished secondary school (Grades 10-12) and thirty-one (41%) had obtained higher education degrees. Approximately 7% finished Grade 9 and only 1.3% was uneducated. The subject studied at higher education level is relevant for pesticide retailers and 27% had studied agriculture while respondents with majors such as chemistry and biology represented around 15%.

Table 6.1 Demographic information of the respondents including number and percentage based on their location, status, years in trading, education level and major of certificate.

Location (Wilaya)	**N**	**%**		**Years in trading**	**N**	**%**
A'Suwaiq	19	25.3		≤5	24	32
Barka	14	18.7		6-10	12	16
Al Kamel	6	8		11-15	11	14.7
Ibri	5	6.67		16-20	12	16
Saham	4	5.33		21-25	7	9.33
Shinas	4	5.33		26-30	3	4
Al Khabourah	3	4		>30	6	8
Al Bureimi	3	4				
Al Hamra	3	4		**Education level**		
Sohar	2	2.67		None	1	1.33
Al Musanah	2	2.67		Grade 9 and less	5	6.67
Nizwa	2	2.67		Grade 10-12	38	50.7
Bahla	2	2.67		Higher education	31	41.3
Izki	2	2.67				
Al Qabil	2	2.67				
Bediyah	1	1.33		**Certificate qualification**		
Yanqul	1	1.33		Yes	31	41.3
Total	75	100		No	44	58.7
Status of respondent				**Major of certificate**		
Owner	12	16		Agriculture	20	26.7
Seller	60	80		Other subject	11	14.7
Worker	0	0				
Other	3	4				

6.4.1.2 Sources of pesticides

Respondents mainly obtained or bought pesticides from a local market. Around 45% of the respondents bought pesticides from wholesalers and about 36% imported pesticides directly from abroad. Around 25% of the respondents purchased pesticides from pesticide company representatives (Figure 6.1).

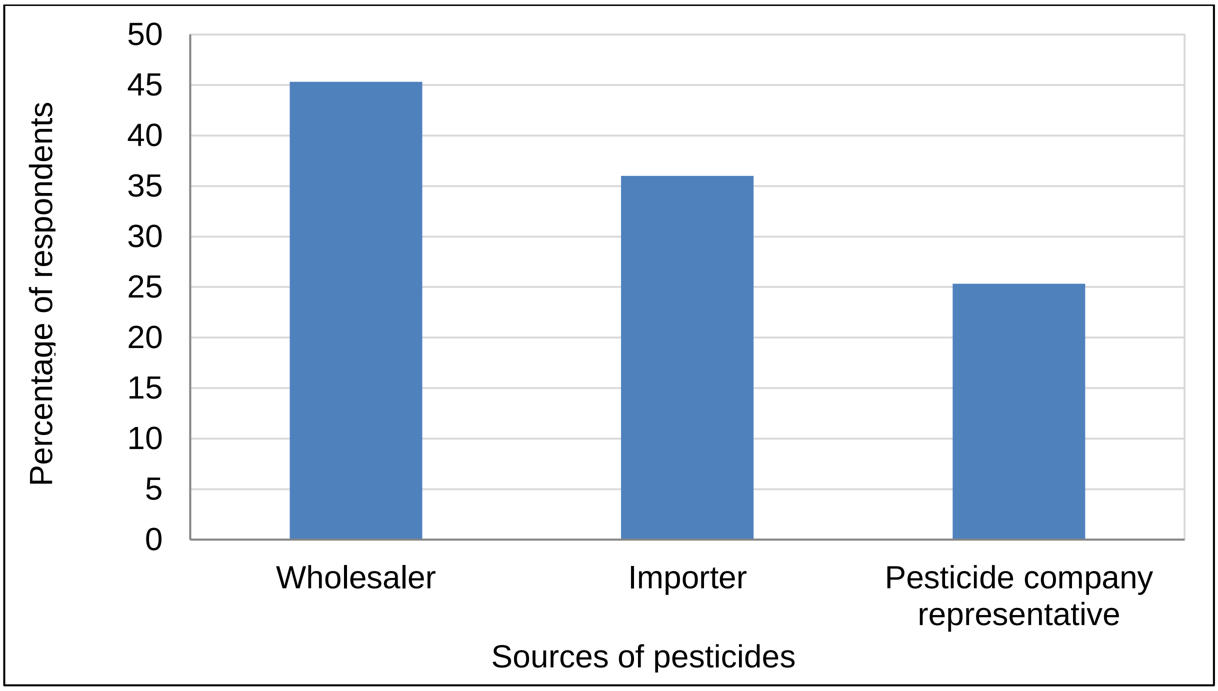


Figure 6.1 Common pesticide suppliers for retailers in Oman. Respondents (n=75) could indicate more than one type of supplier so the total exceeds 100%.

6.4.1.3 Training programs

Training is one of the key elements in developing retailers' capabilities. The percentage of respondents attending training programmes was very low (13%) while 87% of them had never attended any training programme. Four of the 10 training programmes had been provided by pesticide companies (40%) while three were organised by MAFWR, the Ministry of Agriculture and Fisheries and Water Resources (Table 6.2). Three were focussed on about pest control from a public health perspective and three were intended to advertise new products. Only two of the ten programmes discussed the safe use of pesticides and none of the training programmes discussed pesticide application and use. The total number of these programmes was very low (10) considering they had been delivered over a period of thirty-seven years (1980-2017) (Table 6.2).

Table 6.2 Number (N) and percentage (%) of retailers (n=75) who had attended pesticide training together with the training provider, type of training and when it took place.

Attended training?	N	%
Yes	10	13.3
No	65	86.7
Training provider		
Pesticide seller	1	10
MAFWR*	3	30
EA**	2	20
Pesticide company	4	40
Type of training		
Product information	3	30
Pest control	3	30
Safe use of pesticides	2	20
IPM***	1	10
Crop protection	1	10
Pesticide registration and use	0	0
When training was undertaken		
2015-2017	2	20
2011-2014	1	10
2007-2010	1	10
2004-2006	4	40
2000-2003	0	0
1990-1999	1	10
1980-1989	1	10

*Ministry of Agriculture and Fisheries and Water Resources.

**Environment Authority.

***Integrated Pest Management

6.4.1.4 Main sources of pesticide information

Respondents depended on pesticide suppliers as the main source of information about pesticides they sell (85%). Four percent of the respondents obtained this information from other sources such as the internet (Table 6.3). The MAFWR was the source of information for one retailer while two did not know where they got such information from (Table 6.3).

Table 6.3 Retailers' main sources of pesticide information.

Main source for pesticide information	N (n=75)	(%)
Pesticide suppliers	64	85.3
Other	3	4
Farmers and pesticide suppliers	2	2.67
Don't know	2	2.67
MAFWR	1	1.33
Farmers	1	1.33
Farmers, Pesticide suppliers and Others	1	1.33
MAFWR and Pesticide suppliers	1	1.33

6.4.2 Work experience

6.4.2.1 Pest and disease identification

Pest and disease identification are the key element for any crop protection program because correct identification is essential to select appropriate control measures. Most of respondents were able to identify major vegetable crop pests such as spodopteran and whitefly (> 90%). Leaf minor was identified by around 70% of the respondents and 55% of the respondents' diagnosed damping-off. Around 30-45% of the respondents identified other pests and diseases such as aphids, downy mildew, early blight, melon decline, powdery mildew and late blight. Few (12%), however, identified thrips correctly (Figure 6.2). Status, years of trading and location of respondents did not reveal any association with their ability to diagnose pests and diseases ($P > 0.05$, Appendix 36). However, Jordanian retailers revealed a higher ability to diagnose pests and diseases (70.8%) followed by Egyptians (63.6%) and Sudanese (56.8%) whereas the Bangladeshi (29%) and Omani (34.5%) retailers were unable to identify a majority of the crop problems (Table 6.4, $P < 0.001$, Appendix 36). Respondents with a higher education qualification were better at diagnosis (63.3%) than those educated to grades 7-9 (47.3%) or 10-12 (40.4%) (Table 6.4, $P = 0.003$, Appendix 36). Respondents with agriculture certificates performed better (63.3%) than those without this certificate (40.7%) (Table 6.4, $P = 0.014$, Appendix 36). Training showed positive and significant effects. Respondents who had participated in training programmes showed higher ability to diagnose pests and diseases (77.3%) in comparison to those who had never attended any training (45.9%) (Table 6.4, $P = 0.001$, Appendix 36).

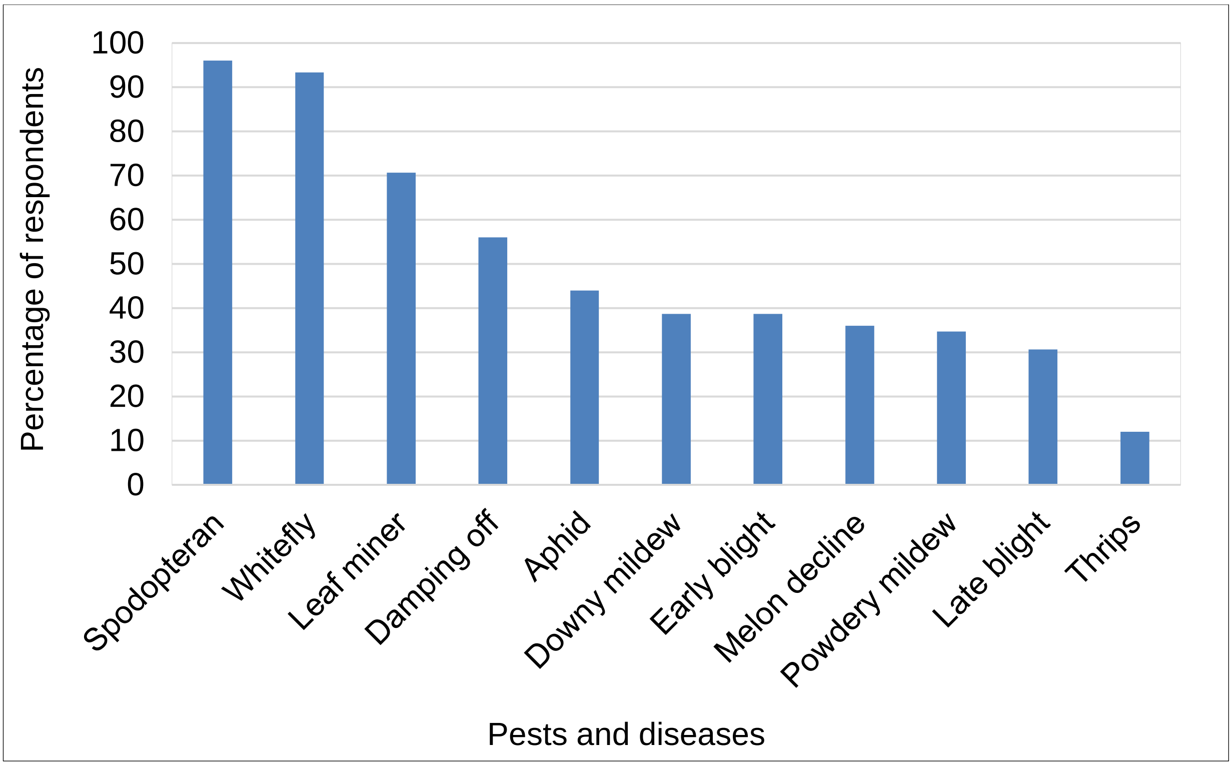


Figure 6.2 Percentage of retailers (n=75) who correctly identified eleven common pests and diseases of vegetable crops.

Table 6.4 Numbers of retailers (n=75) classified according to their nationality, education level, certification and training and their average scores when asked to identify eleven pests and diseases.*

Variable								P
Nationality		Jordanian	Egyptian	Indian	Omani	Bangladeshi	Sudanese	
	Number	19	12	7	15	16	4	
	Average score, %	70.8	63.6	53.2	34.5	29	56.8	< 0.001
Education		Grade 7-9		Grade 10-12		Higher		
	Number	5		38		31		
	Average score, %	47.3		40.4		63.3		0.003
Certificate		Agriculture		Other certificate				
	Number	31		44				
	Average score, %	63.3		40.7				0.014
Training		With training		Without training				
	Number	10		65				
	Average score, %	77.3		45.9				0.001

* Variables with less than three observations were excluded.

6.4.2.2 Appropriateness of pesticide selection

Having identified a crop protection problem, the proper selection of pesticides for controlling the problem is clearly very important. If the selected product is not correct, the problem may not be controlled, excessive amounts may be used risking human exposure and environmental pollution and farmers may incur a financial loss. Respondents revealed a high ability (93.4%) to recommend the appropriate pesticides to control whitefly followed by spodopteran (76.5%) (Figure 6.3). Around 43.4% and 41.9% of appropriate pesticides were recommended to control aphid and leaf miner respectively (Figure 6.3). The lowest proportion of appropriate pesticides (8.82%) was suggested to control thrips (Figure 6.3). However, there was no significant effect of respondent's status, years of trading, location, education level and type of certificate on their ability to recommend the proper pesticides ($P > 0.05$, Appendix 37). Nonetheless, Jordanian respondents had a higher ability to recommend the appropriate pesticides to control the eleven pests and diseases of vegetable crops (66%) followed Egyptians (64.6%) and Indians (52.8%) (Table 6.5). Omani (33.7%) and Bangladeshi (35.5%) respondents revealed the lowest ability (Table 6.5, $P = 0.002$, Appendix 37). Despite trained respondents were better able to suggest appropriate pesticides (68.1%) than non-trained respondents (47.4%), caution need to be taken in consideration since only a small number of respondents (10) had participated in training in comparison to 65 respondents who never attended any training programmes in pesticides (Table 6.5, $P = 0.034$, Appendix 37).

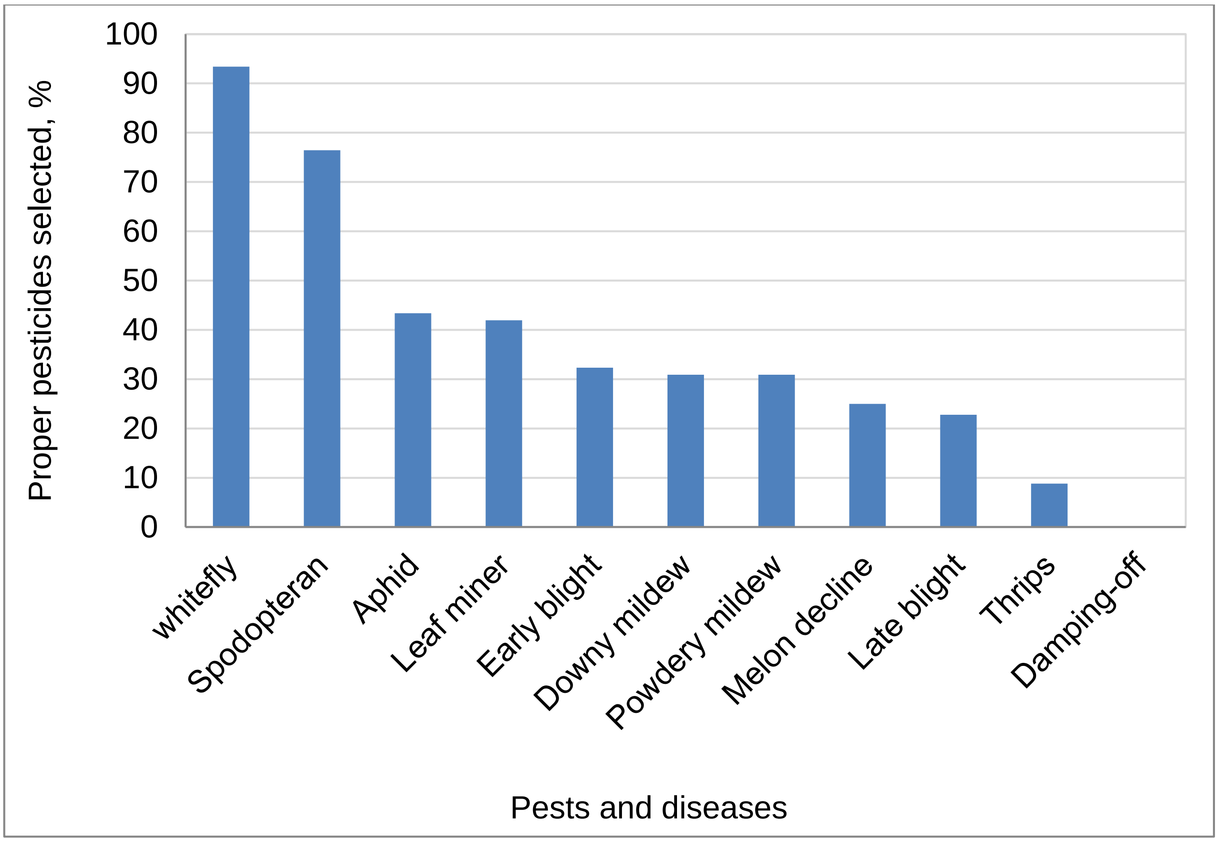


Figure 6.3 Percentage of the appropriate pesticides selected by retailers (n=75) to control whitefly (n=127), spodopteran (n=104), aphid (n=59), leaf miner (n=57), early blight (n=44), downy mildew (n=42), powdery mildew (n=42), melon decline (n=34), late blight (n=31), thrips (n=12) and damping-off (n=51).

Table 6.5 Mean percentage of appropriate pesticide recommended by retailers (n=75) classified according to their nationality and training.*

Variable								P
Nationality		Jordanian	Egyptian	Indian	Omani	Bangladeshi	Sudanese	
	Number	19	12	7	15	16	4	
	Average score, %	66	64.6	52.8	33.7	35.5	52.1	0.002
Training		With training			Without training			
	Number	10			65			
	Average score, %	68.1			47.4			0.034

*Variables with less than three observations were excluded.

Limiting the analysis to cases where a pest or disease had been ***correctly*** identified, most of respondents were able to selected the proper pesticides to control spodopteran (95.1%) and whitefly (93.2%) (Figure 6.4). However, respondents indicated low proportions (around 50%) of appropriate pesticides to control Powdery mildew (52.4%), late blight (51.9%) and downy mildew (46.6%). Although this analysis is restricted to cases where the problems had been identified correctly, very few appropriate recommendations were made to control thrips (10.4%) (Figure 6.4).

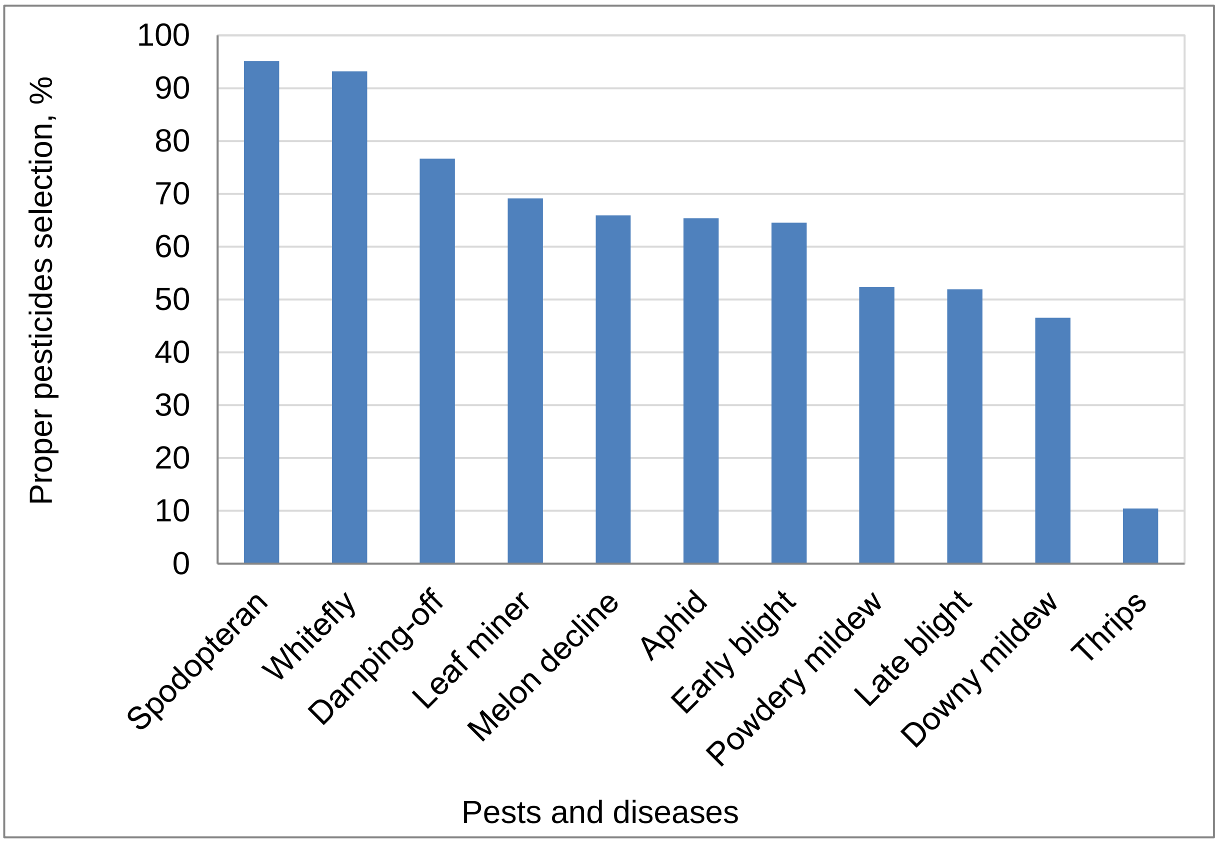


Figure 6.4 Percentage of appropriate pesticides recommended by retailers who had first *correctly* identified the pest or disease for whitefly (n=123), spodopteran (n=97), leaf miner (n=56), aphid (n=51), damping-off (n=46), early blight (n=40), downy mildew (n=34), powdery mildew (n=33), melon decline (n=31), late blight (n=27), and thrips (n=7) were correctly diagnosed. The values of n are the number of correct recommendations. The percentages should be treated with caution for thrips as n<10.

There was a distinctive reduction in the numbers of appropriate pesticides recommended by respondents (≤ 55%) to control various vegetable pests and diseases when the crop problems had not been identified correctly (Figure 6.5). For instance, the highest proportions of appropriate pesticides were recommended to control spodopteran (54.5%) and whitefly (30.8%). Moreover, only 17% and less of appropriate pesticides were recommended to control downy mildew, melon decline, early blight, late blight, thrips and leaf miner (Figure 6.5).

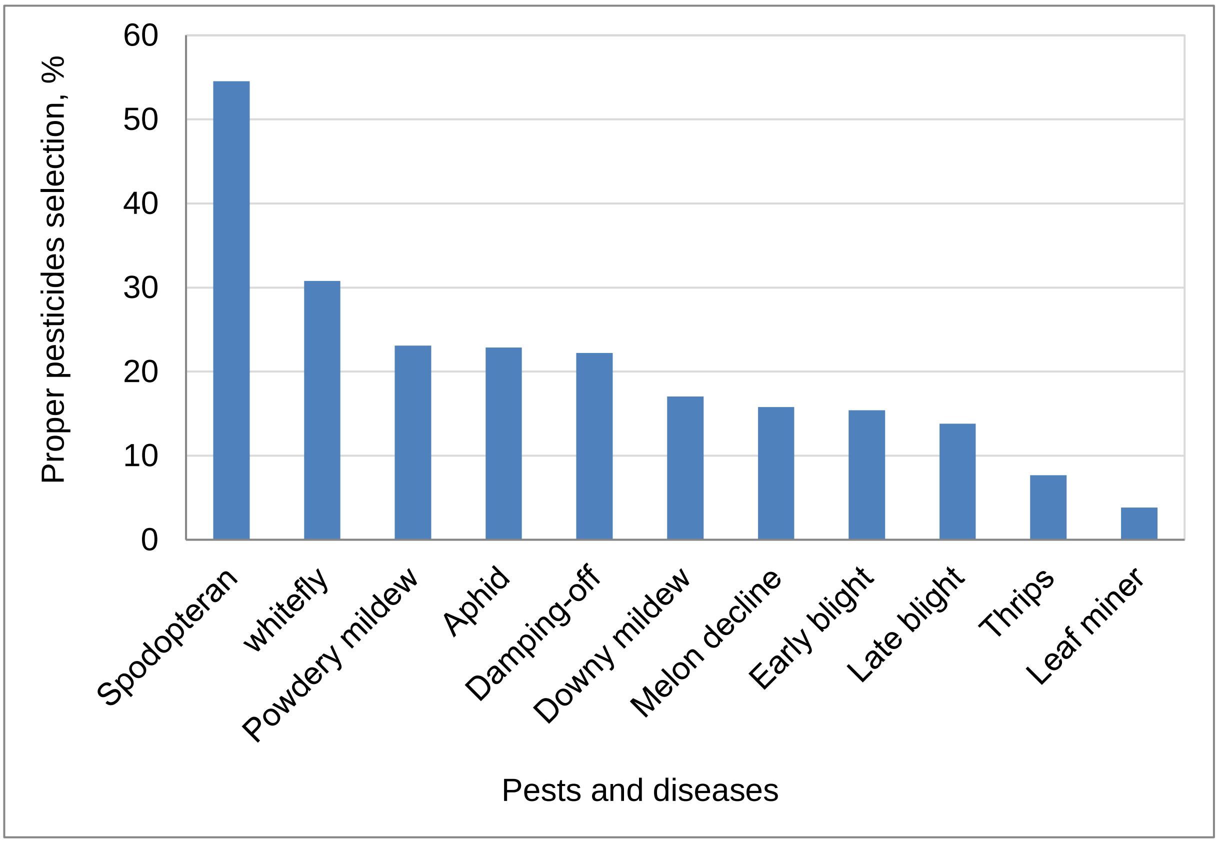


Figure 6.5 Percentages of appropriate pesticides recommended by respondents (n=75) when powdery mildew (n=9), downy mildew (n=8), aphid (n=8), spodopteran (n=6), thrips (n=5), whitefly (n=4), early blight (n=4), late blight (n=4), damping-off (n=4), melon decline (n=3) and leaf miner (n=1) were incorrectly diagnosed.

6.4.2.3 Cases of inappropriate pesticide selection by retailers

In some cases, even when crop problems were diagnosed correctly, respondents suggested wrong pesticides (>50%). In total, 60 pesticides were incorrectly recommended for the eleven pests and diseases. For instance, 46.1% of pesticides were incorrectly suggested by respondents to control thrips pest while around 25% were recommended for late blight disease (Figure 6.6). Even when downy mildew was identified properly, around 17.1% of selected pesticides were incorrect. Proportions of 12.5% and 11.5% of incorrect pesticides were recommended by respondents to control leaf miner and damping-off respectively (Figure 6.6). Spodopteran (4.90%), whitefly (4.65%) and powdery mildew (2.94%) revealed the lowest proportions of incorrect pesticide recommendations (Figure 6.6).

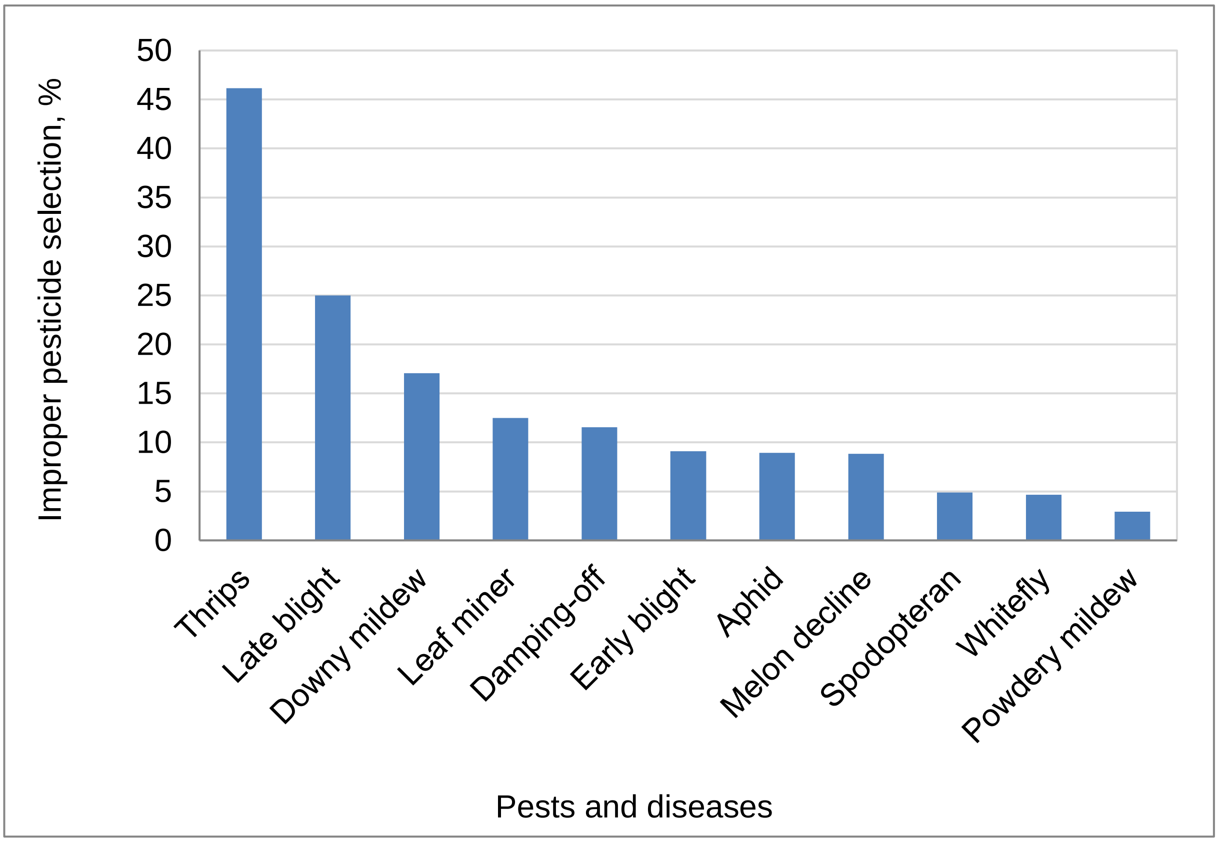


Figure 6.6 Percentage of inappropriate pesticides recommended by respondents (n=75) when late blight (n=9), leaf miner (n=8), downy mildew (n=7), thrips (n=6), whitefly (n=6), damping-off (n=6), spodopteran (n=5), aphid (n=5), early blight (n=4), melon decline (n=3) and powdery mildew (n=1) were correctly diagnosed.

6.4.2.4 Retailers' pesticide dose rate recommendations

Dose or dilution rate (i.e. the amount of active ingredient to be diluted in a known volume of water in the sprayer tank) is normally stated clearly on the label of each pesticide and should be strictly followed by the applicators. In this study, a tolerance of 10% was deemed acceptable so that a 'correct' dose rate is the recommended rate on the label (±10%). Even though respondents could have checked a label while the survey was being administered, 42% of retailers recommended too low a dilution rate (so that the pesticide would be applied above the recommended rate and more pesticide would be used and sold). The proportion of recommendations within 10% of the label dose rates was 36% while there 125 cases (22%) below the dose rate on the label (Figure 6.7). There were no significant effects of respondents' status, years of trading, location, nationality, education level, type of certificate and training on their ability to recommend the proper dose rate of selected pesticides (P> 0.05, Appendix 38).

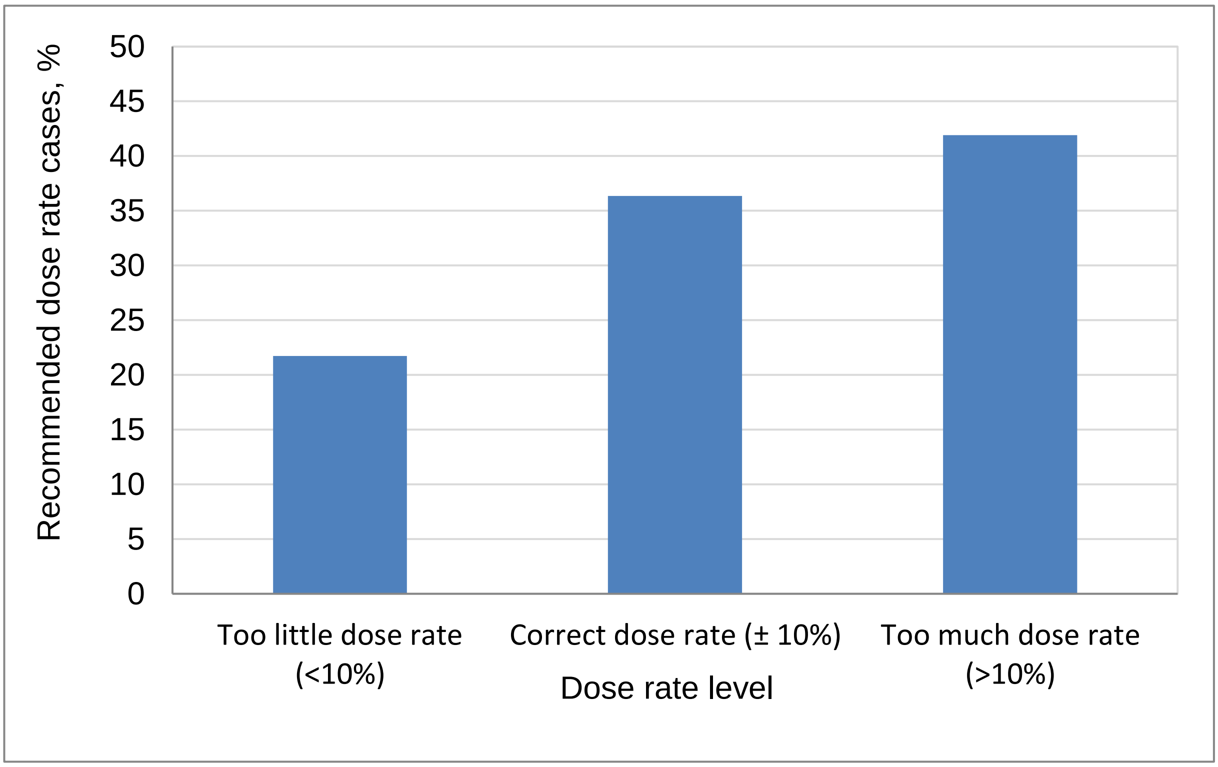


Figure 6.7 Percentage of pesticide dose rates specified by the respondents (n=75) which were close to the label recommendation or more than 10% too low or too high.

Taking in consideration the most common vegetable crops grown in the country (tomato and eggplants), the top three pesticides (acetamiprid, emamectin benzoate and abamectin) that are used to control the most common problems (whitefly, spodopteran and leaf miner respectively) were selected to assess the amount of dose rate variations for each crop and problem. A range of ±10% of the dose rate stated on the local labels was again deemed acceptable. For the acetamiprid, 87% of respondents recommended an appropriate dose rates whereas for emamectin benzoate, less than half (47%) of the respondents suggested an appropriate dose rates while 16% were too low and 37% too high (Figure 6.8). Abamectin pesticide recommendations were much worse with only 10% of the respondents indicating the correct dose rates while most of them (59%) reported lower dose rates and one third suggested higher dose rates than the recommended (Figure 6.8).

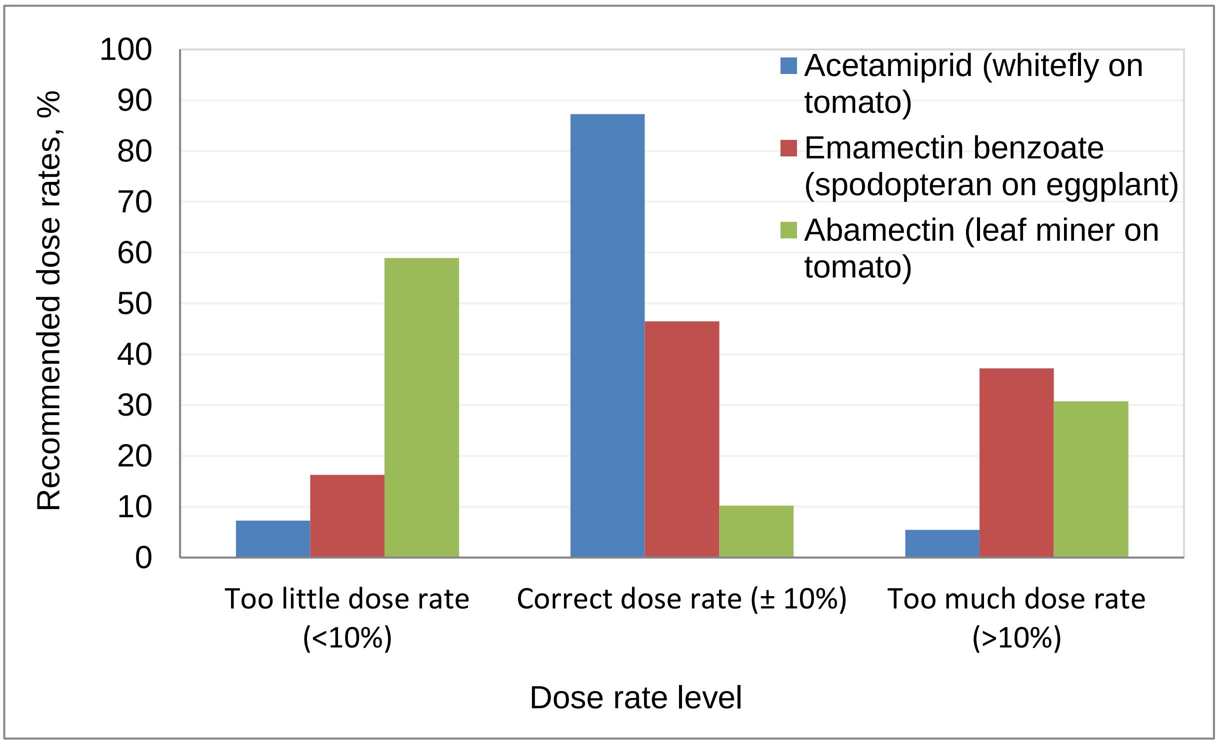


Figure 6.8 Percentages of dose rates specified by respondents which were close to the label recommendation or more than 10% too low or too high for acetamiprid (n=55) to control whitefly on tomato, emamectin benzoate (n=43) to control spodopteran on eggplant and abamectin (n=39) to control leaf miner on tomato crops, where n is the number of retailers recommending the product.

6.4.2.5 Retailers’ recommendations of pre-harvest intervals (PHI)

Pre-harvest intervals refer to the time between the last permitted application date of pesticide and the possible date of harvest. The farmers and retailers should be aware of these intervals because they affect the residue levels of pesticides in the crops after harvest and shortening the interval makes it likely that the MRL (maximum permissible residue limit) is likely to be exceeded rendering the crop unsuitable for consumption. In this study, the correct PHI was deemed to be that stated on the label with a tolerance of ±1day. Retailers’ survey showed that about 76% of the respondents were able to recommend PHI correctly or they failed safe by recommending a longer PHI than that stated on the labels, but 24% stated too short an interval (Figure 6.9). There was no significant effect of respondents’ status, years of trading, location, education level, type of certificate and training on their ability to recommend the proper PHI ($P > 0.05$, Appendix 39). In terms of ethnicity, Egyptian respondents were slightly better able to recommend the proper PHI (31.8%) followed by the Jordanian (25.4%) and Indian (24.1%) respondents (Table 6.6). Omani retailers showed the lowest performance followed by Bangladeshi and Sudanese (Table 6.6, $P = 0.005$, Appendix 39).

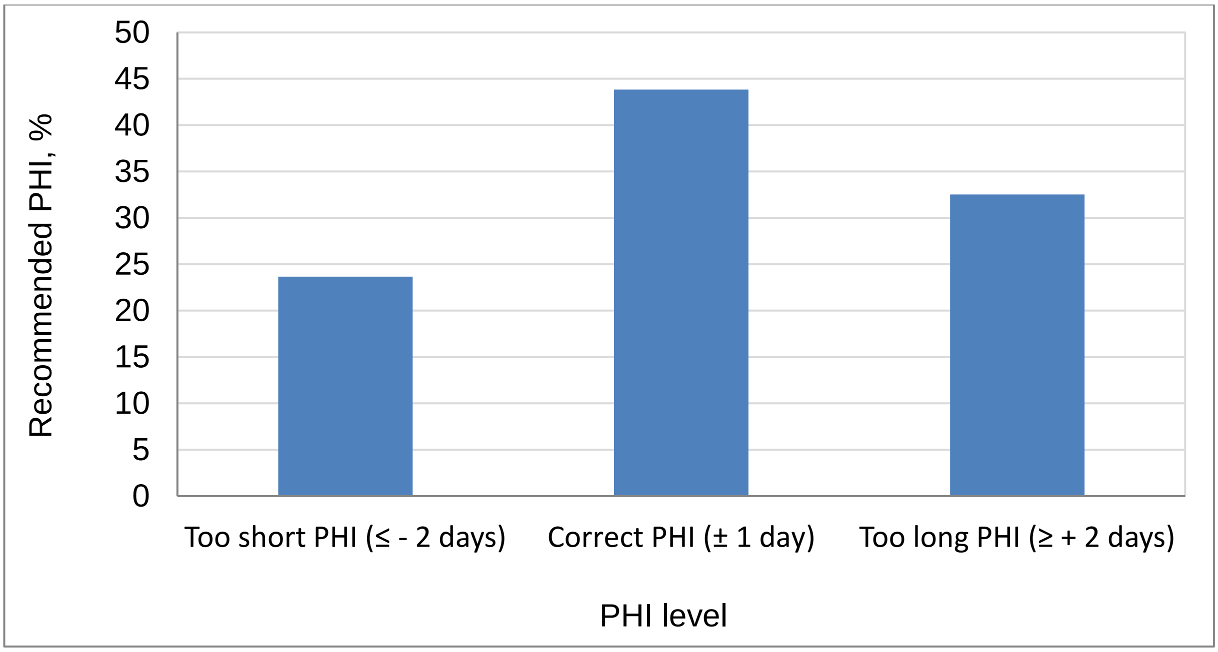


Figure 6.9 Pre-harvest intervals recommended by the retailers (n=75) for the selected pesticides.

Table 6.6 Mean percentages of correct PHI recommendations by retailers classified according to their nationality.*

Variable								P
Nationality		Jordanian	Egyptian	Indian	Omani	Bangladeshi	Sudanese	
	Number	19	12	7	15	16	4	
	Average score, %	25.4	31.8	24.1	10.6	16.6	16.6	0.005

*Variables with less than three observations were excluded.

Considering the most common vegetable crops (tomato and eggplants) and the top three pesticides (acetamiprid, emamectin benzoate and abamectin) used to control the most common problems (whitefly, spodopteran and leaf miners, respectively), the retailers' PHI recommendations were assessed. A range of ± 1day of the PHI was again considered 'correct'. Although the highest proportions of PHI recommendations were correct, 38, 21 and 26% of PHI recommendations were too short for acetamiprid, emamectin benzoate and abamectin, respectively (Figure 6.10).

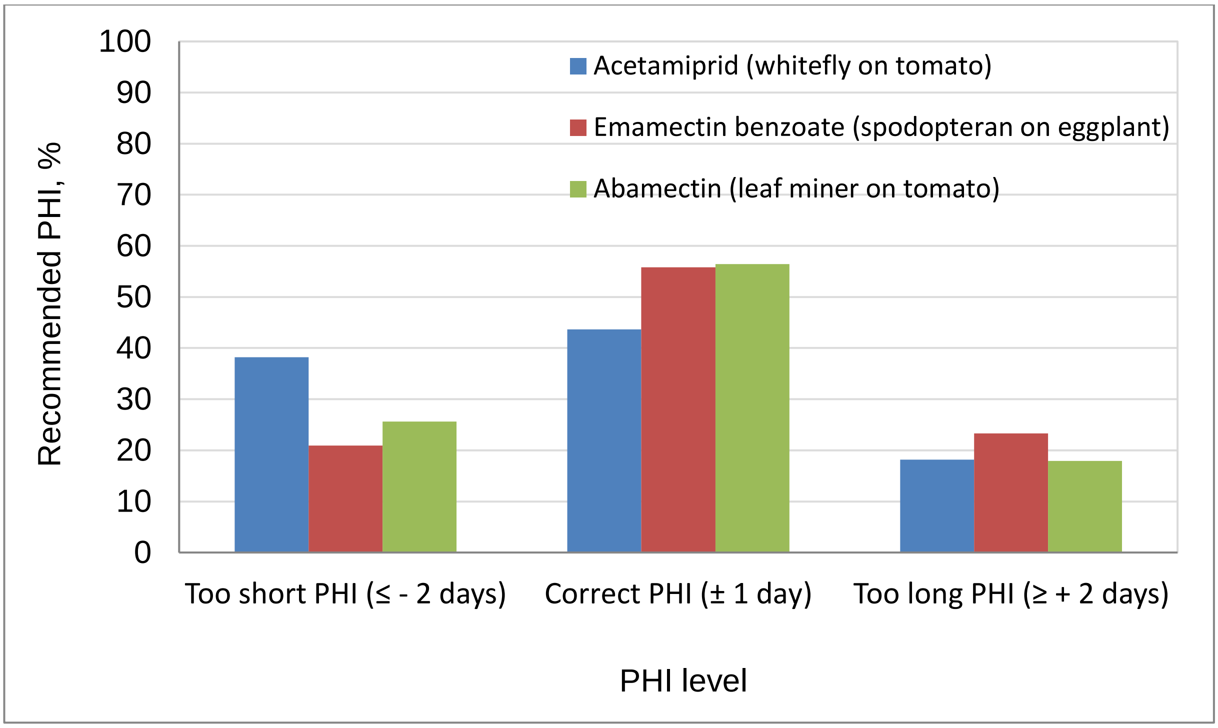


Figure 6.10 Percentages of ‘correct’ (±1 day) and incorrect PHIs recommended by retailers for acetamiprid (n=55) to control whitefly on tomato, emamectin benzoate (n=43) to control spodopteran on eggplant and abamectin (n=39) to control leaf miner on tomato, where n is the number of retailers recommending the product.

6.4.2.6 Pest and disease identification and correct pesticide selection

Correct pest and disease identification is the first step of successfully implementing control measures. For chemical control, the second step is the proper selection of pesticides. The results obtained from retailers’ survey suggested that there was a link between the ability to diagnose pests and diseases and their ability to select an appropriate pesticide (Figure 6.11). As the number of correct identifications increased, the selection of appropriate pesticides also increased, regression relationship being significant (R^2= 0.628, P= 0.014, Figure 6.11).

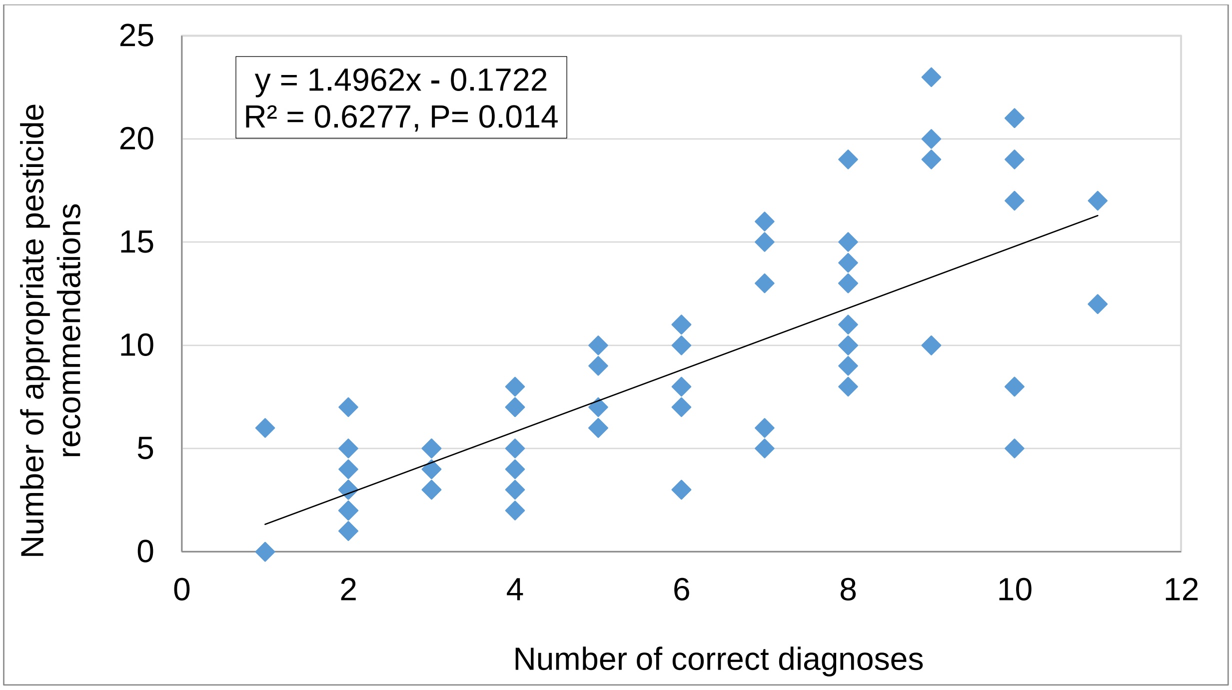


Figure 6.11 Relationship between correct diagnosis of pests and diseases and the selection of appropriate pesticides. Retailers could recommend more than one correct pesticide for a given problem.

6.4.2.7 Selling decision making

Retailers may sell pesticides based on their knowledge and experience if they are asked for advice, or they will products at the buyer's request. An average of 43% of the pesticides sold based on retailer's suggestions (Figure 6.12). Most of the pesticides sold based on farmers desire or understandings (57%).

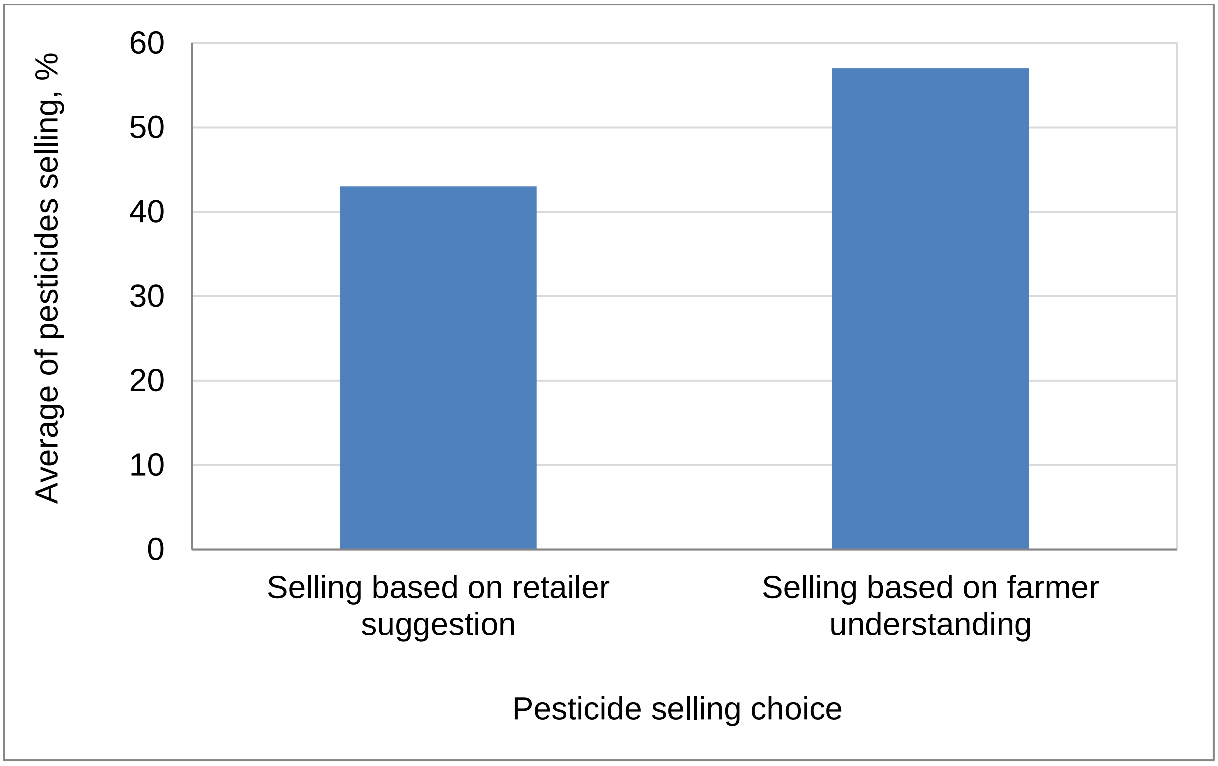


Figure 6.12 Respondents (n=75) responses to the question whether they sell their products mainly based on their suggestions or farmers understanding.

6.4.2.8 Source of diagnostic help

The main source of diagnostic help for farmers on different pests and diseases was obtained from the pesticide sellers (59%). MAFWR, as a governmental authority, represented a help source to 21% of the respondents but around 15% of the respondents did not obtain any help from any source (Figure 6.13). Only 5.33% of the respondents searched in other sources such as internet for diagnostic information. Two retailers (2.67%) obtain diagnostic help from farmers. These results reveal the weakness of governmental extension services as a key agency from which farmers and retailers should be able to get help and support.

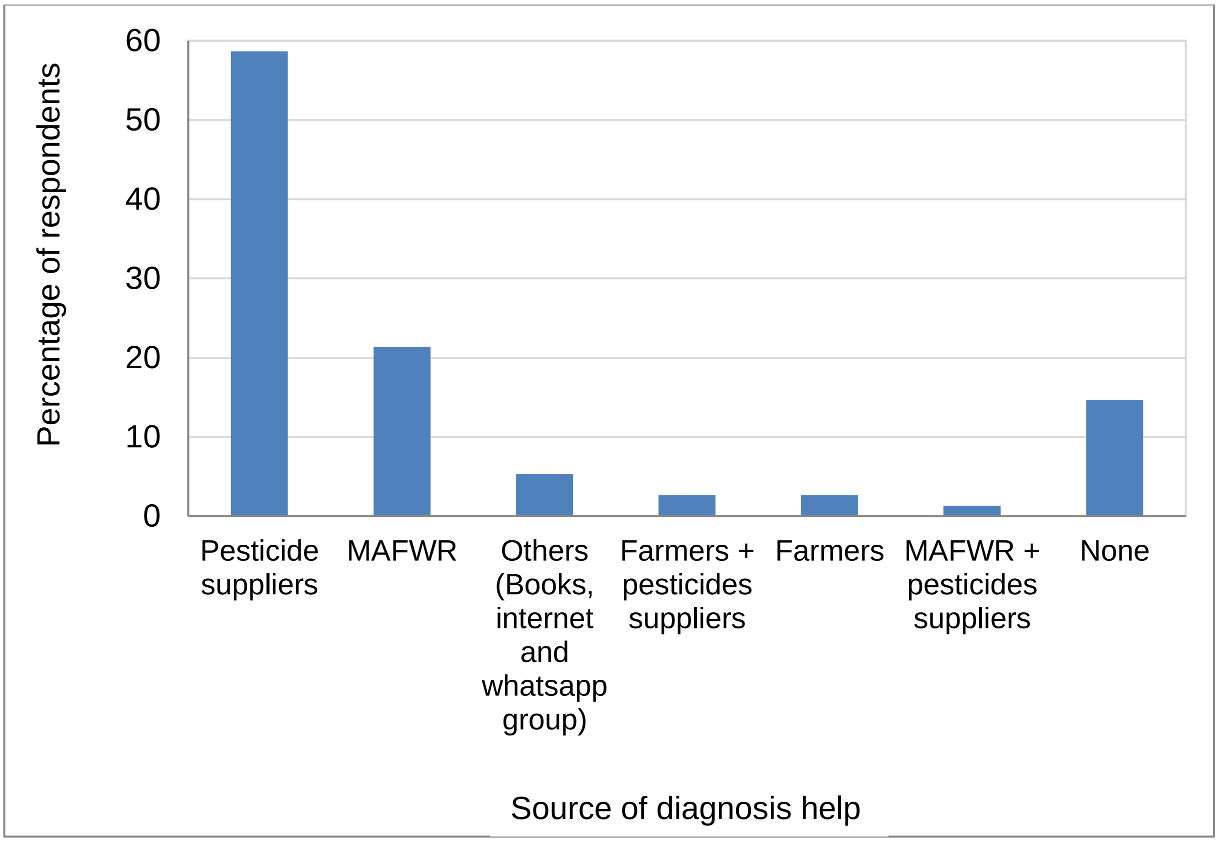


Figure 6.13 Percentage of the retailers (n=75) obtaining diagnostic advice on pests and diseases from different sources. Respondents may indicate more than one source so that the total exceeds 100%.

6.4.2.9 Retailers’ perceptions on ineffective active ingredients

Sometimes and for many reasons, pesticides may not be effective against the pests and diseases they are expected to control. Respondents were asked what action they took in such cases. Nearly half (45.3%) said they would recommend another pesticide while about 30.7% of them would advise the farmers to increase the dose rate and 17.3% suggested checking the application rate (Figure 6.14). Some did not know what to do.

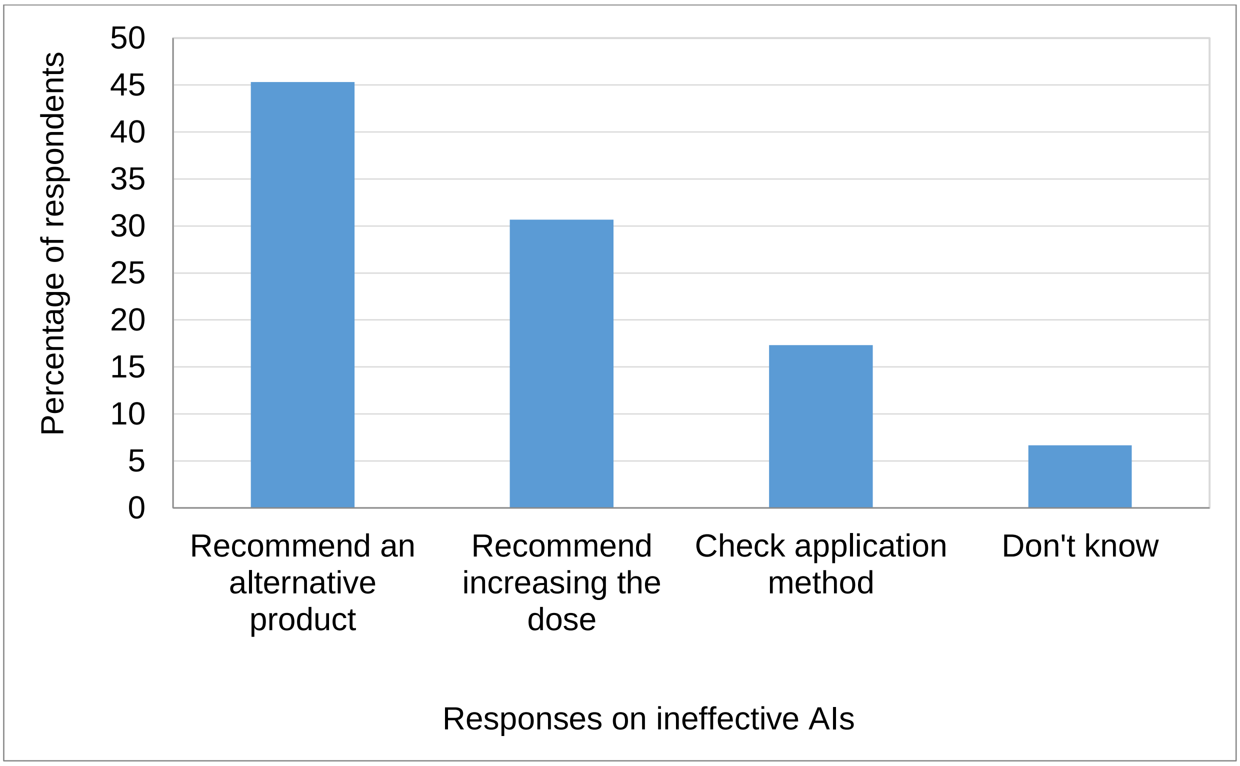


Figure 6.14 Retailers' recommendations to customers on how to tackle ineffective active ingredients (n=75).

6.4.2.10 Retailers and resistance problems

Resistance to pesticides in the targeted pests and diseases is a very critical issue which is mainly related to misuse of pesticides in crop protection. The problem is linked to many factors such as the ability of some pests and diseases to withstand pesticides by a resistance gene and consequently reducing susceptibility to pesticides allowing spread of resistant pests and diseases. About 60% of the retailers had not come across any resistance problems in the area where they provided retailing services but about 40% were aware of such problems. Most of the respondents directed the buyers to change the products if they faced any resistance problem (73%) (Table 6.7). About 7% of the respondents did not know how to deal with resistance and some would advise that farmers should either increase the pesticide dose or check the method of application was 13.3% (Table 6.7) Most of the respondents (66.7%) did not know the reasons of resistance occurrence. However, frequent use of the same active ingredients represented 16%. Some of them referred to a genetic change in the organism as a reason (8%) while two respondents blamed poor quality of pesticides as the reason behind resistance and four respondents referred to dose rate (Table 6.7).

Table 6.7 Numbers and percentages of retailers' awareness of resistance cases in their areas, their recommendations to farmers to tackle resistance problems and explanation of resistance occurrence.

Awareness of pesticide resistance	Number (n=75)	%
Yes	31	41.3
No	44	58.7
Suggestions of retailers to farmers encountering resistance occurrence		
Recommend a different product	55	73.3
Recommend increasing the dose	5	6.67
Don't know	5	6.67
Check the application method	5	6.67
No resistance has occurred	4	5.33
Not aware of any such cases	1	1.33
Explanation of retailers for occurrence of resistance in pests and pathogens		
Don't know	50	66.7
Frequent use of the same active ingredient	12	16
Genetic change in the target organism	6	8
Dilution issues	4	5.33
Poor quality products	2	2.67
Poor water quality	1	1.33

The respondents who revealed the presence of resistance in their areas suggested some examples listed in Table 6.8. Tomatoes were reported to have the highest incidence of resistance with four cases followed by melon and the forage crop, alfalfa with three cases each. Mites (8), fruit worms (7) and whiteflies (7) were the most frequently mentioned as exhibiting resistance. Eleven active ingredients were associated with resistance among which deltamethrin was the most frequently reported (13) followed by Abamectin (6) and Acetamiprid (4) (Table 6.8).

Table 6.8 Numbers of resistance problems for crops, pests and diseases and active ingredients reported by retailers in their areas.

Crop	Number of reports by retailers
Tomato	4
Melon	3
Alfalfa	3
Cucumber	2
Egg plant	2
Date palm	1
Pest/Disease	
Mites	8
Fruit worm	7
Whitefly	7
Spodopteran	2
Downy mildew	2
Fruit fly	1
Aphid	1
Dubas bug	1
Termite	1
Wilt	1
Leaf curl	1
Active ingredients	
Deltamethrin	13
Abamectin	6
Acetamiprid	4
Emamectin benzoate	2
Chlorpyrifos	1
Metalaxyl	1
Malathion	1
Fosetyl-Alumenium	1
Fenpyroximate	1
Abamectin + Chlorantraniliprole	1

6.4.3 Retailers' perceptions on health and safety measures for pesticides

6.4.3.1 Retailers' awareness of possible risks of pesticides.

Respondents revealed a good awareness of the risks associated with pesticide use and ≥80% realised there were risks to livestock, wild life and human health (Figure 6.15). Over half (53%) understood that there were also possible risks of pesticides to soil and water and out of the 75 respondents, only 13.3% of them did not acknowledge that pesticide use may cause any adverse effect to humans and the environment components (Figure 6.15). There were no significant effects of years of trading, education levels and training of respondents on their awareness of the potential risks of pesticides to humans and the environment (P> 0.05, Appendix 40).

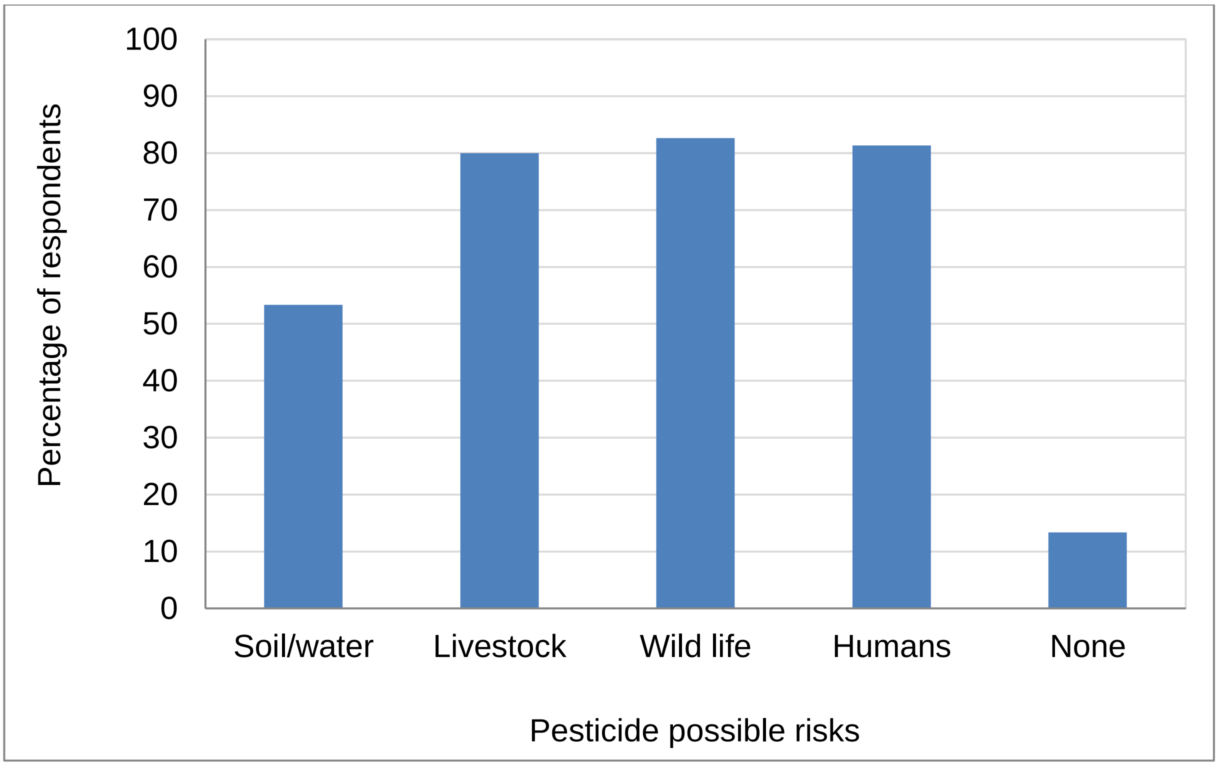


Figure 6.15 Percentage of retailers (n=75) who believed there were risks of pesticides to humans and the environmental components.

6.4.3.2 Explanation of possible risks of pesticides.

Most retailers showed a clear understanding that improper use of pesticides could harm humans, livestock and the environment. Nevertheless, around 36% of them “never” or “rarely” explained these risks to their customers (buyers). Around 23% of the respondents said they “sometimes” explained these risks to the buyers. Under half of the respondents (41%) indicated that they “usually” or “always” explained the possible risks of pesticides to the buyers before selling them the pesticides (Figure 6.16). There were no significant effects of years of trading, education levels and training of respondents on their explanation of the potential risks of pesticides on humans and the environment to their customers when selling pesticides (P> 0.05, Appendix 41).

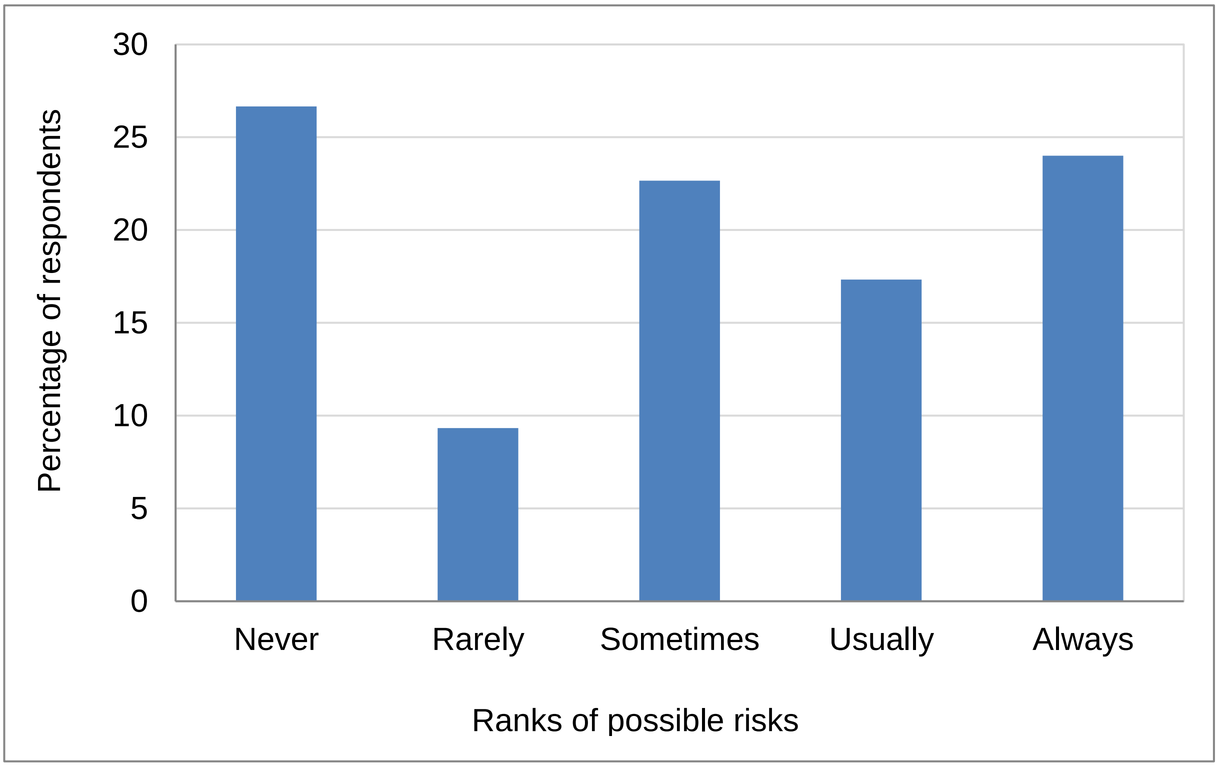


Figure 6.16 Regularity with which respondents (n=75) explain the possible risks of pesticides to their customers before selling them.

6.4.3.3 Protective measures and personal adverse effect

There are many problems associated with pesticide handling in the work environment related to lifting, storing, loading and offloading. These possible problems or risks may include leakage and spills. Nevertheless, only two of the 75 respondents took any protective measures while handling pesticides in their retailing business (97%). A similarly high percentage (97%) claimed never to have encountered any adverse effect of pesticides on themselves as a result of their work (Table 6.9).

Table 6.9 Retailers' response to protective measures they took and any personal adverse effect they encountered at work environment.

	Protective measures at work		Personal adverse effect	
	N (n=75)	%	N (n=75)	%
Never	73	97.3	73	97.3
Rarely	0	0	1	1.33
Sometimes	0	0	1	1.33
Usually	2	2.67	0	0
Always	0	0	0	0

6.4.3.4 Retailers' responses to the question: "Do you read safety instructions on pesticide labels before selling them?".

Most of the respondents (41.3%) revealed that they "never" and "rarely" read the safety instructions that are stated on the labels of pesticide containers (Figure 6.17). Around 18.7% of the respondents indicated that they "sometimes" read those instructions. Respondents who "usually" and "always" read the labels safety instructions represented 34.7% of the 75 total respondents. There was no significant effect of years of trading of respondents on their decision to read safety instruction before selling pesticides ($P > 0.05$, Appendix 42). The education level of respondents had a significant effect on the respondents' decision to read the safety instructions before selling the pesticides. The difference was between higher education and grade 10-12 respondents (Table 6.10, $P = 0.002$, Appendix 42). Moreover, training showed a significant effect on the respondents' decision to read the safety instruction before selling pesticides. Respondents who attended any training programmes read the instructions more than non-trained respondents (Table 6.10, $P = 0.032$, Appendix 42).

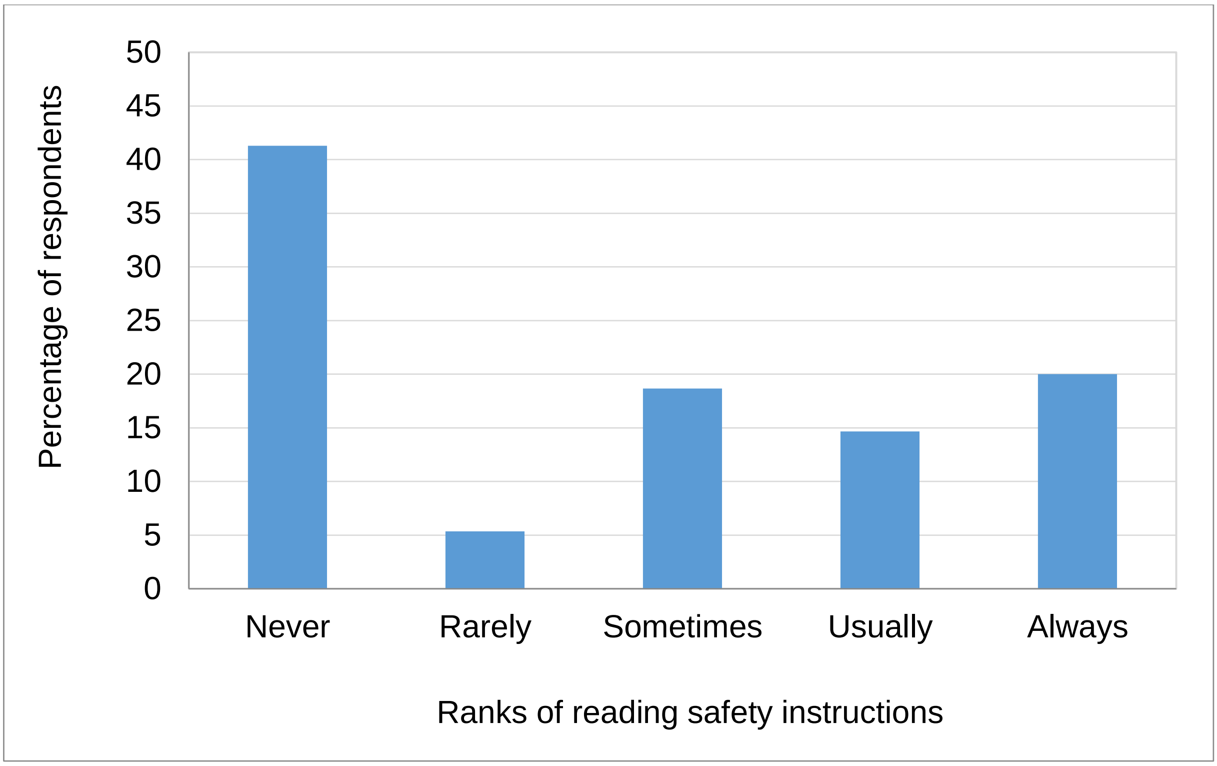


Figure 6.17 Percentage of respondents (n=75) reading pesticide label safety instructions before selling them.

Table 6.10 Numbers and percentages of respondents (n=75) responses to the reading of safety instructions based on their education levels and training.

Variable		%			P
Education level		Grade 9 and lower (n=6)	Grade 10-12 (n=38)	Higher (n=31)	0.002
	Never	50	63.2	12.9	
	Rarely	0	5	6	
	Sometimes	16.7	10.5	29	
	Usually	16.7	5	25.8	
	Always	16.7	15.8	25.8	
Training		Training (n=10)	Without training (n=65)		0.032
	Never	0	47.7		
	Rarely	10	5.6		
	Sometimes	30	16.9		
	Usually	30	12.3		
	Always	30	18.5		

6.4.3.5 Retailers' perceptions on expired pesticides and empty containers

Disposing of expired pesticides and empty containers is one of the critical issues in minimising the risks of pesticides worldwide. In Oman, disposal of expired pesticides is a serious problem due to a lack of approved companies or facilities in the country to perform the incineration and disposal in the recommended way. A third of the retailers disposed of expired pesticides in the Municipal waste sites while 25% of them returned them to the suppliers. Several respondents (16%) claimed not to have come across expired pesticides and about 13% of them reported their need for pesticide waste disposal to the MAFWR. One retailer admitted that he changed the label. For empty containers, most of the respondents (75%) said they never had to deal with empty containers in their shops and 21% of them dispose empty containers in Municipal site. Only 4% of them burn empty containers (Table 6.11).

Table 6.11 Responses of retailers (n=75) to how they deal with expired pesticides and empty containers in their shops.

	Dealing with expired pesticides		Dealing with empty containers	
	N	%	N	%
Dispose in Municipal site	25	33.3	16	21.3
Return to supplier	19	25.3	0	0
Does not occur	12	16	56	74.7
Inform MAFWR	10	13.3	0	0
Bury	5	6.67	0	0
Burn	3	4	3	4
Change label	1	1.33	0	0
Repackage/reuse	0	0	0	0

6.4.3.6 Retailers' ability to identify pesticide label safety symbols

Identifying safety symbols on pesticide labels reflects an awareness of the safety precautions that pesticide applicators should follow before and after spraying to protect themselves from exposure to pesticides. Retailers should not only understand these symbols, but also they should be able to explain the meaning and importance of these safety precautions to buyers when they are asked. Data analysis reveals that retailers showed a high ability in identifying pesticide pictogram safety symbols. Most of the retailers (above 80%) were able to identify symbols of gloves, face shield, boots, wash after spray and use of overalls. Less than 40% of retailers were able to identify the symbols for proper spraying and proper storage (Figure 6.18). There were no significant effects of the years of trading, education levels and training on the ability of respondents to identify the seven pictogram safety symbols stated on the lower part of the pesticide labels shown to them (P> 0.05, Appendix 43).

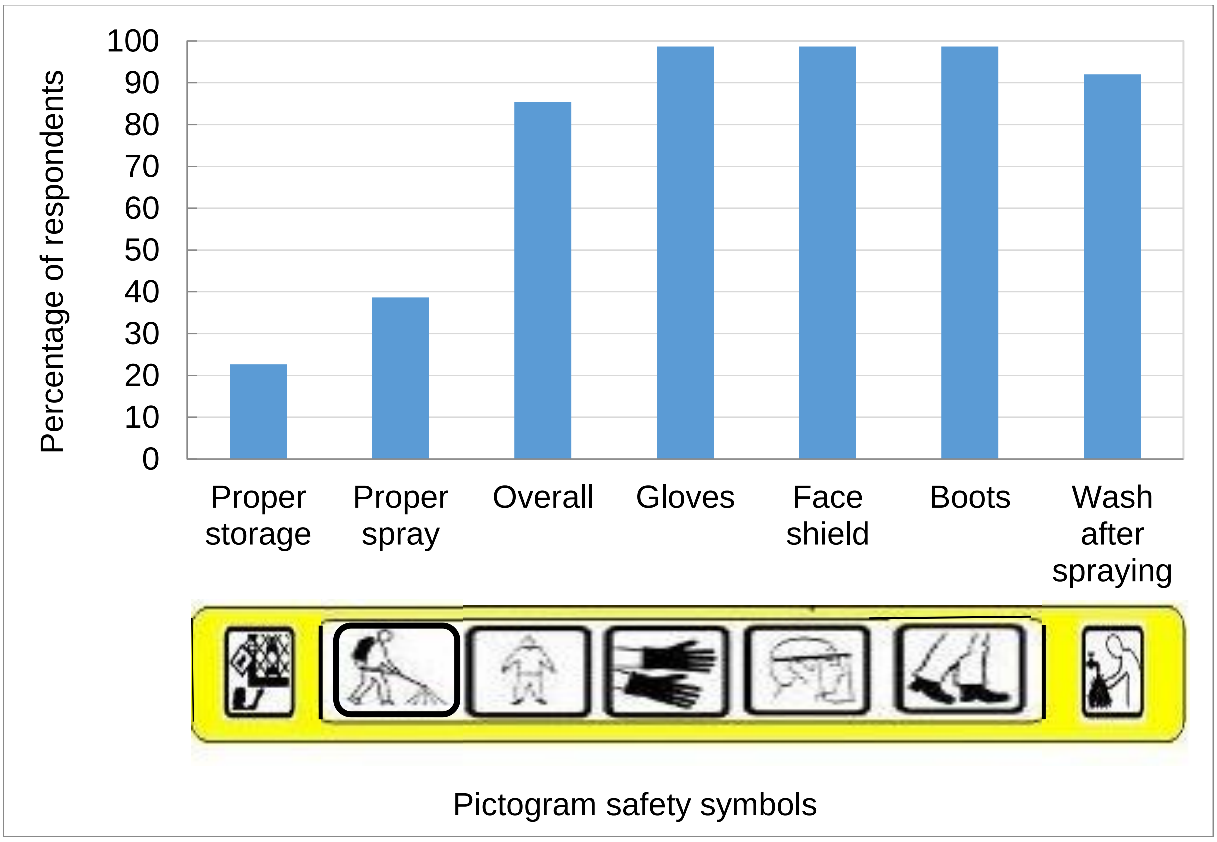


Figure 6.18 Retailers ability to identify safety symbols on pesticide labels.

6.4.3.7 Retailers awareness on banned and restricted pesticides

Retailers also need to be familiar with is the lists of banned and restricted pesticides issued by MAFWR. These lists specify the active ingredients that are not allowed to be used or can only be used in restricted ways. Most retailers (80%) were unaware of any banned and restricted pesticides. However, twenty percent of the respondents did know that MAFWR issued lists of banned and restricted pesticides.

6.4.3.8 Are retailers interested in research results?

Although the retailer survey guaranteed the participants' anonymity, most were not interested in the research results (63%) and only 37% were interested.

6.5 Discussion and conclusion

6.5.1 Discussion

The research has shown that pesticide retailers play a major role in farming in Oman. The actual numbers of licensed pesticide retailers in Oman was 152 up to the end of 2020 (chapter 1). However, this study focuses on all the retailers in the seven governorates where this research was carried out. The number of retailers needs to be updated annually because this business sector is affected by supply and demand dynamics in the market. Some of the retail shops may open for a short period of time before they shift to another place or close. Sometimes the number may increase rapidly if there is an intensification of farming in an area (Stadlinger et al., 2013) or due to weak or lack of governmental or private sector extension services (Jin et al., 2015). Pesticide retailers in Oman, as in many other parts of the world (Haj-Younes et al., 2015), have not been studied in depth even though they are a key stakeholder in the pesticide industry in the country. Based on the findings of this study, most of the respondents surveyed were sellers rather than the business owners. It was also found that many of the retailers surveyed have operated in this business for less than five years suggesting they only had a few years of experience. Retailers were quite well educated with approximately 41% having obtained higher degrees and half of them having completed Grades 10-12.

In Oman, retailers must meet article 4 of the Pesticide Law 64/2006 which states that: “It is not allowed to import, manufacture, handle (including selling, transport and storage) any pesticide unless a license is obtained from the relevant authority”. They should also fulfil article 43 of the Pesticides Implementing Regulation 41/2012 which states that: “Pesticide handling license applicator should provide a copy of the labour contract of the agricultural technician, engineer or expert who will work in the shop in addition to a copy of his qualification”. The firm or the shop which does not fulfil these two articles of the pesticide law and regulation is considered illegal.

Pesticide suppliers were found to be the main source of pesticide information for retailers and there was little information provided to them from the government which points towards poor channels of communication between MAFWR and the retailers.

Unlike developed countries, the situation in developing countries is quite complicated. The relationship between retailers and government bodies does not encourage cooperation and mutual trust. The government office issues licences to the retailers and it is entitled to monitor their selling practices in order to enforce pesticide laws and regulations. Many governments worldwide are concerned about law enforcement but give less value to cooperation with other stakeholders through sharing ideas, information and practices to improve the overall knowledge and awareness of all parties.

Since retailers represent the major source of information to farmers (Chapter 3), improving the ability of retailers to diagnose various pests and diseases, recommend proper pesticides with correct application information in addition to advising the farmers on the proper health and safety measures that they need to take before, during and after pesticide applications is imperative. However, although farmers depend on retailers as a major source of information and advice on crop protection, retailers are businesses and the actual sellers have as their main target, the sale of agriculture products and it is unrealistic to expect them to want to educate farmers on how to deal with crop protection issues or pesticides unless that will help them to close a sale. It seems there is a major weakness in the pesticide management system in the country in different governmental and non-governmental levels.

Identification of pest and disease is the first step to successful application of any control measures. In Chapter two, it was shown that many FA and nFA farmers got help in pest and disease diagnoses from retailers. The quality of that advice needs to be reviewed because most of the retailers were able to identify three pests (spodopteran, whitefly and leaf miner) out of the eleven problems shown to them but less than half could identify the other pests and diseases. Moreover, the low ability of some retailers to identify most of the pests and diseases indicates the need for training to improve their diagnostic ability.

More than half of the retailers were, however, able to recommend the proper pesticides for the pests and diseases shown to them. Yet, there was a significant number who were unable to recommend the correct pesticides - a consequence of their failure to identify most pests and diseases correctly. For instance, although the pests and diseases were correctly identified, forty six percent or less of retailers suggested pesticides for controlling specific pests and diseases when the latter were not recommended on the label, which indicates an unsatisfactory level of knowledge on proper pesticide selection. It is noteworthy that, inappropriate selection of pesticides may lead to several adverse consequences including to humans and the environment not to mention the waste of time, efforts and money by the farmers and risk of accumulating pesticide residues on vegetables. The situation in Oman is therefore similar to that in Bangladesh where retailers provided very shallow information or guidelines to the farmers (Ali et al., 2020). However, it is clear that correct identification of crop problems improved the ability of retailers to recommend the proper pesticides.

The recommended dose rate is stated clearly on the label of each product and retailers should be able to explain the instructions of use to farmers when they ask to obtain this information especially for new products. In this study, retailers often suggested dose rates above or below the recommended rates and this were observed for different active ingredients used to control different pests and diseases attacking different crops. However, a similar findings was reported by Van Hoi et al. (2013) in Vietnam where retailers were found to be violating labelling regulations. This could be attributed to the technical information that retailers obtained from pesticide suppliers. Additionally, overdosing could also be due to the low quality of the products or resistance development. The quality control of products must be monitored by the government either through batch to batch analysis or on a random basis to ensure the products quality meets global specifications approved by FAO or products' manufacturers.

Pre-harvest intervals must also be observed to avoid exceeding maximum permissible pesticide residues in food products. Although most of the retailers suggested the correct or longer PHIs, which reflects a good understanding of importance of PHI for food safety, around one third of them suggested shorter periods leading to a risk to human health. Retailers' suggestions of shorter PHI was not limited to a specific type of active ingredient or a specific crop problem or crop and so appeared to be a more common and general practice. Farmers may also contribute to this problem by preferentially selecting pesticides with shorter PHIs. PHI suggestions below the label recommendation were also reported for retailers in Vietnam (Van Hoi et al., 2009).

Various factors may contribute to retailers giving incorrect information to the farmers. Among these, there were no significant effects of retailer's status, years of trading, location of the companies or shops and education level. There was, however, a significant difference between retailers of different nationalities in pests and diseases diagnosis ability, correct pesticide selection and correct PHI recommendations. Jordanian and Egyptian retailers showed better performance than others. The main reason for this variation was the label's language. Pesticide labels that contain the table of use including crops, targeted pests or diseases, dilution rate and PHI were written in Arabic language which could be difficult to decode and understand by non-Arabic speakers such as Bangladeshi, Indian and Pakistani retailers.

Although two of the Omani retailers had certificates, neither of them was qualified in agriculture or chemistry and this could account for their poor knowledge of label information in comparison to the Jordanian and Egyptian retailers. However, some retailers may not read what is written on the labels, depending instead on oral instructions from the pesticide suppliers. In other cases, expatriate retailers may be familiar with what they saw or used in their home country and they may use the same information in Oman.

Education levels produced some significant effects on retailers' ability to identify pests and diseases but it did not significantly improve the correct pesticide selection, dilution rate and PHI recommendation. Dealing with crop protection issues like pests and diseases identification and pesticide selection and application requires an agricultural background in order for the retailer to identify the problem first then suggest the proper pesticide to the farmers to control the problem. The pesticide regulation requests a specific certificate in the field of agriculture for pesticide importers to grant them licences and stated that a diploma in agriculture or a relevant subject is essential for the retailers to be licensed. Nonetheless, over half of the retailers (59%) did not hold such a certificate which means that the laws and regulations relating to sales of pesticides are neither being observed or enforced. However, this seems to be a common challenge as the same situation has been reported in other countries including Lebanon (Salameh et al., 2004), China (Zhang and Lu, 2007), Ethiopia (Mengistie et al., 2015) and Iran (Neghab et al., 2018).

Training yielded significant benefits on retailers' capabilities to identify pests and diseases and propose the correct pesticides but it did not improve their recommendations of dilution rates and PHI. Training is therefore an important factor that improves retailers' knowledge, perceptions and work experiences, but the content of such programmes clearly needs to be reviewed and strengthened to ensure all stages in the pesticide cycle are included. Training programmes could also mitigate the effects of a lack of education among retailers. Although the number of training programmes was low, most of those who had participated in such programmes were able to identify more than seven pests and diseases out of eleven. Untrained respondents showed varied abilities to identify these problems. Some of them were unable to identify more than one pest or disease. Results revealed a significant effect of training on the ability of respondents to identify the eleven major pests and diseases attacking vegetable crops in their areas. These results highlight the importance of training of all pesticide stakeholders including retailers which supports similar recommendations in other countries (Fan et al., 2015, Mengistie, et al., 2016 and Vaidya et al., 2017).

There was a positive correlation between correct pest and disease diagnosis and proper selection of pesticides. These findings revealed the importance of crop problems identification as a determining factor for proper pesticide selection.

Most of the respondents were frequently selling pesticides based on farmers' understanding rather than on their suggestions. This revealed the past and long experience of farmers in controlling pests and diseases attacking their crops during growing seasons. Frequent pest resurgence of the same problems over seasons and the use of the same active ingredients or brand names of pesticides may build the farmers' accumulated knowledge about the pesticides they need to buy.

If farmers reported a pesticide was not working, most of the retailers would recommend alternative products or increase dose rates; perhaps because they would prefer to sell more and different pesticides rather than going to the farm and trying to understand why the product did not work. Around 17% of the retailers suggested checking the application method which sounds reasonable but this needs to be improved through training programs. Nonetheless, the possibility of resistance occurring, which was highlighted by some of the responses, merits further investigation in a more detailed questionnaire. This questionnaire should explore whether the farmers or retailers come across frequent resistance cases each season and if the resistance occurs with one crop/pest or disease or for different crops and pests or diseases and whether the product fails to control the problem in part of the field or the entire field and is the same problem found in neighbouring fields and farms. Some retailers suggested increasing dose rates to deal with possible cases of resistance, which is unwise since increasing the concentration may lead to negative consequences such as pesticide residues in the crops and it may also exacerbate any resistance. It may also cause phytotoxicity, environmental pollution, human risks and financial loss. Thus, the weakness or the lack of an adequate and technically professional extension service could lead retailers to encourage the farmers to overuse pesticides as in China, where inadequate agricultural extension services have been considered the most important external factor for the overuse of chemical inputs including pesticides (Sun et al., 2012).

Most of the retailers had not, however, encountered any cases of pesticide resistance. The lack of a tracing or reporting system for resistance occurrence probably explains this result since most retailers simply suggested using an alternative or a different pesticide when farmers reported that a pesticide had failed to work. In addition, there are many active ingredients available in the market for each individual pest or disease making resistance occurrence invisible in many cases. Nonetheless, the questionnaire administered in this research did not investigate the occurrence of resistance deeply so it is unclear why respondents attributed a failure of control to resistance. However, thrips, spodopteran and whitefly were considered as common pest that developed resistance to frequently sprayed insecticides such as deltamethrin and abamectin. Spraying the same chemicals over many seasons for the same crop develops resistance against pests and diseases (Gisi and Leadbeater, 2010). A pesticide stewardship scheme designed to reduce the risk of resistance development in Omani farms is essential and a joint effort by government extension service, the FA and the retailers could be the main source of information to facilitate the end users in seeing the importance of adopting such a scheme to prevent loss of active ingredients due to resistance.

Most of the retailers exhibited positive perceptions and a favourable understanding of pesticide risks to humans and the environment. This may be ascribed to their education level and years of experience. The majority of the retailers had completed at least grade 9 at school which reflects their ability to read and understand the health and safety instructions stated on the pesticide labels. Training did not yield any effect on the retailers' explanation and perceptions of possible risks to humans and environment associated with pesticide use. However, although retailers understood the potential risks of pesticides to humans and the environment, most of them did not take or recommend any protective measures when they sold pesticides. Clearly, the retailer wants to sell a product. They won't have time or inclination to spend much time explaining risks as that might reduce sales or mean that another customer has to wait to be served. Another reason for not using any safety measures could be due to the minimal accidents they had encountered in the past; a finding also reported by Bhandari et al. (2018). It could also be due to the lack of government enforcement of pesticide regulations to ascertain retailers' adherence to the stipulations related to work environment, pesticide storage and packaging.

A significant number of retailers did not read the safety instructions stated on the pesticide labels compromising their role in advising farmers on the health and safety precautions required. The effect of education level and training was significant revealing a better commitment of educated and trained retailers in comparison to retailers with lower education levels. This demonstrates the importance of both education level and training programmes to increase the awareness and implementation of health and safety issues related to pesticide handling, selling and applications. Nonetheless, as a business firm, targeting profit, we should not expect retailers to read the safety instructions at the point of closing a sale. They may need to do that at first time since the instructions are almost similar. On other hand, the end users may need to read these instructions before use in order to avoid adverse side effects.

This study concluded that more than one third of the retailers disposed of the expired pesticides in the municipal sites, while others buried, burned or returned them to the suppliers. However, only a few retailers asked the MAFWR to assist them in disposing of the obsolete products in the recommended way which is another symptom of the weak communication channels between MAFWR and retailers. However, article 60 of the pesticide regulation 41/2012 instructs all pesticide firms including pesticide sellers to inform MAFWR when they want to dispose of any expired or obsolete pesticides. The MAFWR signed an agreement with Food and Agriculture Organization (FAO) to dispose all obsolete pesticides that exist in the country by shipping them abroad to be incinerated and disposed of in a proper way that does not cause any harm to humans and environment. Nevertheless, most of the pesticide retailers are not committed to the pesticide regulation revealing an ignorance of the laws and/or a disregard for the human and environmental health and safety. It is reported that these expired products can cause pollution to the environment (Hajjar, 2015 and Kosamu et al., 2020) and may become toxic to the humans if they leach into the underground water or if vapours are inhaled by people living near to the storage site or near burning or burying areas (Dvorská et al., 2012).

Although empty containers are not present in large quantities in the retail shops or stores, yet many retailers dispose of these containers in the Municipal sites which is illegal and reveals an ignorance of pesticide regulations among some retailers who should contact MAFWR regarding the disposal process. The same practice was also reported in Tanzania by Lekei et al. (2014) who concluded that unqualified retailers are unlikely to be able to advise farmers on safe practices such as the proper disposal of empty containers.

Most of the retailers were able to identify the seven safety symbols on the pesticide label pictograms. Symbols of proper spraying and appropriate storage were the least well identified symbols whereas the symbols of wearing gloves, overall, boots, face shield and washing after spraying were very clear and easily identified. It seems that retailers were not giving attention to the safety procedures which pesticide end users need to follow before, during and after spraying. This may also explain why many retailers “Never” or “Rarely” explained the potential risks of pesticide use to humans and the environment to the end users.

This study revealed the weakness or absence of the communication channel between the local authorities (MAFWR) represented by extension services and the retailers. Many respondents may not, therefore, have any information about banned or restricted lists of pesticides which were issued by MAFWR in 2007 and then revised and included in the pesticide regulation 41/2012. These lists are appended in the document of the pesticide law and regulation issued by MAFWR in 2013 and it should have been disclosed and made accessible to all retailers since it was enforced from the date of issue. A similar situation was found in Cambodia where Schreinemachers et al. (2015) reported that interviewed retailers were unaware that the government had banned certain pesticide products.

Surprisingly, most retailers did not want to be told about the survey results. Reasons for this lack of interest were not explored, but it raises questions about the retailers' perceptions and attitudes.

These findings should function as an alert to all stakeholders about the urgent requirement to provide retailers with extensive, stringent and holistic training programmes in pest and disease identification, pesticide selection and application and health and safety issues.

6.5.2 Conclusions

The hypothesis of this chapter is that:

> Retailers vary in their ability to diagnose pests and diseases, to recommend appropriate pesticides and application procedures and to recognise the adverse effects of pesticides on humans and environment.

The objective of this chapter is to investigate the pesticide retailers' perceptions and knowledge of pest and disease diagnosis, pesticide selection and application and health and safety measures. This study results indicated the following:

1. Retailers differed in their ability to identify the major vegetable pests and diseases, select the proper pesticides, determine the correct dose rate and pre-harvest intervals and recognition of health and safety measures. The basic hypothesis was therefore accepted.
2. Factors associated with the better performance among retailers included:
   a. Their nationality – Jordanian retailers performed particularly well compared to Bangladeshi and Omani retailers.
   b. Education level – Respondents who were educated above grades 10-12 gave better advice.
3. Type of certificate and training – Retailers with an agriculture-based education or who had received training performed better. These findings could be influenced by the use of Arabic on pesticide labels which is a barrier to non-Arabic speakers.
4. Although most of the retailers understood the potential harm of pesticides to humans and environment, they tended to ignore the safety procedures they should follow in their stores and they generally did not explain them to their customers.

In conclusion, there is an urgent need to provide the retailers with extensive, stringent and holistic training programmes in the pest and disease identification, pesticide selection and application and in health and safety issues. It is also important that MAFWR, academic institutions, and non-governmental organisations such as the FA take a much more active role in dissemination of information on pesticide use. Although the law and rules require the pesticide sellers to adhere to the legal statements, but it is importance to educate and trained them on improve their awareness and practices so they can share such experience with end users.

Based on the findings, the hypothesis was accepted and it is clear there is a wide range of competency among retailers and there were a significant number of cases where they would be likely to sell incorrect products and provide erroneous or unsafe advice.

6.6 Recommendations

There is a need to:

1. Design holistic training programmes for retailers to improve the awareness and practices of pests and diseases diagnosis, pesticide selection and application including how to dispose of empty pesticide containers and obsolete pesticides safely so as to avoid environmental hazards and on precautions needed during application to protect the health and safety of their customers and consumers.

2. Rephrase the language of pesticide labels to be understandable by all retailers and farmers including non-Arabic speakers. A separate leaflet in different languages should be developed containing all the information of targeted crops, pests and diseases, application/dilution rate, PHI and other information. It should be printed by pesticide suppliers and provided to the retailers.

3. Improve the technical capabilities of government extension officers to support the retailers and farmers in the diagnosis of crop protection problems, proper pesticides application and in how to handle pesticides safely.

4. Establish strong communication channels between MAFWR and retailers to promote the enforcement of pesticide laws and regulations.

6.7 References

Ali, M. P., Kabir, M. M. M., Haque, S. S., Qin, Z., Nasrin, S., Landis, D., Holmquist, B. and Ahmed, N. (2020) ‘Farmer’s behavior in pesticide use: Insights study from smallholder and intensive agricultural farms in Bangladesh’, *Science of the Total Environment*, 747 (2020) 141160.

Al Zadjali, S., Morse, S., Chenoweth, J. and Deadman, M. (2014) ‘Factors determining pesticide use practices by farmers in the Sultanate of Oman’, *Science of the Total Environment*, 476–477, pp. 505-512.

Bergmann, R. and Ludbrook, J. (2000) ‘Different outcomes of the Wilcoxon-Mann-Whitney test from different statistics packages’, *American Statistician*, 54, pp. 72-77.

Bhandari, G. Atreya, K., Yang, Z., Fan, L. and Geissen, V. (2018) ‘Factors affecting pesticide safety behaviour: The perceptions of Nepalese farmers and retailers’, *Science of the Total Environment*., 631–632, pp. 1560-1571.

Damalas, C. A. and Khan, M. (2016) ‘Farmers’ attitudes towards pesticide labels: Implications for personal and environmental safety’, *International Journal of Pest Management*, 62, pp. 319-325.

Dvorská, A., Šír, M., Honzajková, Z., Komprda, J. Čupr, P., Petrlík, J., Anakhasyan, E., Simonyan, L. and Kubal, M. (2012) ‘Obsolete pesticide storage sites and their POP release into the environment-an Armenian case study’, *Environmental Science and Pollution Research*, 19, pp. 1944-1952.

Fan, L. Niu, H., Yang, Z., Qin, W., Bento, C. P. M., Ritsema, C. J. and Geissen, V. (2015) ‘Factors affecting farmers’ behaviour in pesticide use: Insights from a field study in northern China’, *Science of the Total Environment*., 537, pp. 360-368.

Gisi, U. and Leadbeater, A. (2010) ' The challenge of chemical control as part of integrated pest management', *Journal of Plant Pathology, 92, pp. 11-15.*

Gwet, K. L. (2011) 'Practical guide to statistics: Application with excel, R, and calc. Advanced Analytics Press, LLC.

Hajjar M. J. (2015) ‘Obsolete Pesticides in Saudi Arabia: Problems, prevention and disposal’, *MedCrave Online Journal of Toxicology, 1,* 00009.

Haj-Younes, J., Huici, O. and JØrs, E. (2015) ‘Sale, storage and use of legal, illegal and obsolete pesticides in Bolivia’, *Cogent Food and Agriculture*, 1, 1008860.

Hoi, P. V., Mol, A. and Oosterveer, P. (2013) ‘State governance of pesticide use and trade in Vietnam’, *NJAS - Wageningen Journal of Life Sciences*, 67, pp. 19-26.

Hoi, P. V., Mol, A. P. J., Oosterveer, P. and van den Brink, P. J. (2009) ‘Pesticide distribution and use in vegetable production in the red river delta of Vietnam’, *Renewable Agriculture and Food Systems*, 24, pp. 174-185.

Huang, Y., Luo, X., Liu, D., Du, S., Yan, A. and Tang, L. (2021) ‘Pest control ability, technical guidance, and pesticide overuse: Evidence from rice farmers in rural China’, *Environmental Science and Pollution Research, (In publication).*

Jin, S., Bluemling, B. and Mol, A. P. J. (2015) ‘Information, trust and pesticide overuse: Interactions between retailers and cotton farmers in China’, *NJAS - Wageningen Journal of Life Sciences*, 72, pp. 23-32.

Kesavachandran, C. *et al.* (2009) ‘Health risks of employees working in pesticide retail shops: An exploratory study’, *Indian Journal of Occupational and Environmental Medicine*, 13, pp. 121-126.

Kosamu, I., Kaonga, C. and Utembe, W. (2020) ‘A critical review of the status of pesticide exposure management in Malawi’, International Journal of Environmental Research and Public Health, 17, 6727

Lekei, E. E., Ngowi, A. V. and London, L. (2014) ‘Pesticide retailers’ knowledge and handling practices in selected towns of Tanzania’, *Environmental Health: A Global Access Science Source*, 13, pp. 1-9.

Lyman Ott, R. (1993) 'An introduction to statistical methods and data analysis', Duxbury Press, California, USA.

Mengistie, B. T. *et al.* (2015) ‘Information, motivation and resources: the missing elements in agricultural pesticide policy implementation in Ethiopia’, *International Journal of Agricultural Sustainability*, 13, pp. 240-256.

Mengistie, B. T., Mol, A. P. J. and Oosterveer, P. (2016) ‘Private environmental governance in the Ethiopian pesticide supply chain: Importation, distribution and use’, *NJAS - Wageningen Journal of Life Sciences*, 76, pp. 65-73.

Mubushar, M., Aldosari, F. O., Baig, M. B., Alotaibi, B. M., Khan, A. (2019) 'Assessment of farmers on their knowledge regarding pesticide usage and biosafety’, *Saudi Journal of Biological Sciences*, 26, pp. 1903-1910.

Neghab, M. Jalilian, H., Taheri, S., Tatar, M. and Zadeh, Z. H. (2018) ‘Evaluation of hematological and biochemical parameters of pesticide retailers following occupational exposure to a mixture of pesticides’, *Life Sciences*, 202, pp. 182-187.

Panuwet, P., Siriwong, W., Prapamontol, T., Ryan, P. B., Fiedler, N., Robson, M. G. and Barr, D. B. (2012) ‘Agricultural pesticide management in Thailand: Status and population health risk’, *Environmental Science and Policy.*, 17, pp. 72-81.

Salameh, P. R., Baldi, I., Brochard, P. and Abi Saleh, B. (2004) ‘Pesticides in Lebanon: A knowledge, attitude, and practice study’, *Environmental Research*, 94, pp. 1-6.

Schreinemachers, P., Afari-Sefa, V., Heng, C. H., Dung, P. T. M., Praneetvatakul, S. and Srinivasan, R. (2015) 'Safe and sustainable crop protection in Southeast Asia: Status, challenges and policy options', *Environmental Science & Policy,* 54, pp. 357-366.

Schreinemachers, P. *et al.* (2017) ‘Too much to handle? Pesticide dependence of smallholder vegetable farmers in Southeast Asia’, *Science of the Total Environment*., 593–594, pp. 470-477.

Stadlinger, N., Mmochi, A. J. and Kumblad, L. (2013) ‘Weak governmental institutions impair the management of pesticide import and sales in Zanzibar’, *Ambio*, 42, pp. 72-82.

Sun, B., Zhang, L., Yang, L., Zhang, F., David Norse, D. and Zhu*, Z.* (2012) ‘Agricultural non-point source pollution in China: Causes and mitigation measures’, *Ambio*, 41, pp. 370-379.

Vaidya, A. Gyenwali, D., Tiwari, S., Pande, B. R. and JØrs, E. (2017) ‘Changes in perceptions and practices of farmers and pesticide retailers on safer pesticide use and alternatives: Impacts of a community intervention in Chitwan, Nepal’, *Environmental Health Insights*, 11. pp. 1-12.

Weng, C. Y. and Black, C. (2015) ‘Taiwanese farm workers pesticide knowledge, attitudes, behaviors and clothing practices’, *International Journal of Environmental Health Research*, 25, pp. 685-696.

Yang, X. Wang, F., Meng, L., Zhang, W. and Fan, L. (2014) ‘Farmer and retailer knowledge and awareness of the risks from pesticide use: A case study in the Wei River catchment, China’, *Science of the Total Environment*., 497–498, pp. 172-179.

Zhang, H. and Lu, Y. (2007) ‘End-users’ knowledge, attitude, and behavior towards safe use of pesticides: A case study in the Guanting reservoir area, China’, *Environmental Geochemistry and Health*, 29, pp. 513-520.

Chapter 7. General Discussion and Recommendations.

7.1 Introduction

The main objectives of this study were to compare between farmers who were members of Farmers’ Association (FA) and others who were not members (nFA) in their ability to identify common vegetable crops pests and diseases and to select the appropriate pesticides to control these problems and apply pesticides in proper way. The study also investigated the ability of both farmer groups to identify the potential human and environmental risks and their perceptions of the health and safety measures needed for pesticide application and handling. In addition, pesticide seller insights and practices on pest and disease identification, pesticide selection and application and health and safety measures, were also studied. The importance of this thesis lies in being the first study of its kind to understand farmers’ practices on crop protection in general and pesticide application in particular in Oman. The tremendous and redundant use of pesticides in the production cycle of any crop is very critical due to many implications for humans and the environment. Previous studies have reported a rudimentary use of PPE in vegetable farms in Oman (Thacker et al., 2000) which lead to some health symptoms in Al Batinah coastal area due to pesticide exposure (Esechie and Ibitayo, 2011). In addition, some research investigated some of the environment impacts of pesticide use such as disposal of pesticide waste (AL Zadjali et al., 2013). Moreover, pesticide usage practices and factors affecting farmers’ decision-making and the effect of FA as a means of knowledge diffusion were also investigated and proved (Al Zadjali et al., 2014). However, the lack of trusted sources of information may divert farmers to seek knowledge from other less trustworthy sources. It was reported that the state extension service suffers from insufficient staffing and a lack of training programmes which in turn divert farmers to seek information from the private sector such as pesticide sellers or retailers (AL Zadjali 2009). As described above, most of the previous research focused in the environmental implications of pesticides and studies were concentrated on farmers’ practices and perceptions in only one area (Al Batinah). It was clear from these results that there was a need for deeper investigation of farmers’ perceptions and application of pesticides in Al Batinah and other governorates to understand better the real situation within a wider range of farms with respect to crop protection. Hence, this thesis aimed to answer several questions.

7.2. Summary of findings (Research questions)

1. Can farmers diagnose the common pests and diseases of the vegetable crops and what factors affect their ability to identify the problems?

The proper identification of pests and diseases is considered as the first successful step in the implementation of any control strategy. FA members were better able to identify most of the pests and diseases attacking their vegetable crops in comparison to nFA farmers. Nonetheless, significant numbers of FA members were not able to identify some by the problems properly. However, the ability of nFA farmers to identify most of the problems was very low (<40%) which raises the alarm for the need of improving both groups' diagnostic abilities.

The potential factors that may affect the farmers' identification ability were elucidated. Higher status, a more advanced education level and a larger farm size were found to be more associated with a higher ability. The FA farms managed by owners or tenants were also better able to identify the problems than those managed by the owners and tenants of nFA. The higher education levels of FA respondents gave them the preference to access more information sources and to identify most of the problems in comparison to the less well-educated nFA respondents. Crop diversification of large-scale farms may enlarge the number of crop problems encountered per season, which was found to increase FA farmers' ability to diagnose problems than nFA farmers with smaller-scale farms. However, age, agriculture experience, training, location and source of advice were found to be less associated. However, although the training factor was not found as a more associated factor of difference between FA and nFA farmers in their ability to diagnose the crop problem, only a very few farmers had participated in any training programmes from both groups. Hence, training could be considered as a vital recommendation from this research. In Cameroon, among farmers who were members of a farmers' group or association, only 36% had attended a workshop and 13% a training programme on vegetables and their crop protection (Okolle et al., 2016). It is, therefore, recommended that there is a need to improve farmers' awareness, knowledge and skills to diagnose the economically important pests and diseases attacking their crops and which may cause severe losses to vegetable production. These problems could be tackled through designing a country crop protection programme including pests and disease diagnosis, improving the technical capabilities of governmental extension services, and introducing mandatory training programmes for all stakeholders including retailers who advise farmers in crop protection issues.

2. Can FA and nFA farmers select the appropriate pesticides and apply them according to the labels' recommendations?

Pesticides are very important agricultural inputs because every farmer must control various crop pests and diseases. The global quantities of pesticides used are increasing due to intensive agriculture farming and increasing demand. The local situation of farmers in each country determines the factors affecting pesticide application worldwide. Factors such as education level, certification, training, location, crops, experience, pesticide retailers, suppliers or sellers, pesticide manufacturers, governmental and non-governmental organisations are all different factors that may affect farmers' attitudes, knowledge and perceptions towards pesticide selection, application, storage and handling, disposal of empty containers and obsolete products and other health and safety issues. However, according to Fan et al., (2015), the factors that affect farmers' behaviour in pesticide use are far more complex than expected. Although vegetable farmers had high levels of knowledge about pesticides, they tended to use more pesticides to guarantee high crop yields. In addition, the large gap of trust which exists among farmers, pesticide retailers, and the government which was found to exacerbate the problem (Fan et al., 2015). Moreover, about 15% of the global cultivated areas is planted with fruits and vegetables, but the amounts of pesticides used are three times higher for vegetable and fruit crops than for grain crops (Van Hoi et al., 2009). In Oman, the pesticide selection and application studies are very limited. Very few papers were found that focus on farmers' practices and most of them concern health and safety issues. In this study, there was no difference between FA and nFA farmers in their ability to recommend the proper pesticide for the eleven pests and diseases and there were no effects of age, education level, pesticide experience, training, location and farm size on the respondents' ability to recommend the proper pesticides. These results may indicate that many farmers do not regard the selection of the correct pesticide as very important and they are happy to depend on the advice of the pesticide sellers. This may account for the frequent observation of pesticide sellers' representatives visit farmers and offering their help. In such cases, farmers do not need to seek technical support or a second opinion from governmental extension offices. The accuracy of the information provided to farmers in relation to the pesticide to be used, its dose rate and PHI and other information, depends on the technical competence of the pesticide seller. Moreover, pesticide sellers work for businesses which need to make a profit and want to sell products rather than direct the farmers to the best way of selection and application. Training the farmers in the best pesticide practices seems the only way to achieve the proper selection and application of pesticides amongst all farmers' groups. Training is the work need to be done by governmental extension service with collaboration with farmers' associations. In addition to training, the high-pressure machines (3.73 kW) that were observed used by farmers need to be evaluated and preferably phased out based on the spatial variability observed. Farmers were observed using the same type of machines with same spraying gun and nozzle types and size and without any calibration prior to spraying. The failure of farmers to reach the targeted application rate and/or attain a uniform deposition of pesticides on plants can be explained by the types of machines they were using and the method of application employed.

3. Are the farmers aware of the potential adverse effects of pesticides on humans and the environment?

The research showed that most of the FA farmers were aware of the risks of pesticides to humans and the environment but a smaller proportion of nFA were aware. However, awareness of potential risks associated with pesticide handling and use, does not indicate that farmers adhere to health and safety measures they ought to take before, during and after pesticide use. The majority of FA and nFA farmers disclosed that they "never" or "rarely" used any sort of PPE when applying pesticides.

The same findings were also reported earlier in Oman by Thacker et al (2000) and Esechie and Ibitayo (2011) who also reported some adverse effects of pesticides on farmers which indicated their reluctance to use PPE and avoid exposing themselves to pesticide risks. Although more FA farmers indicated that they read the label's safety instruction than nFA, neither group took the safety instructions into consideration while handling pesticides. The ignorance of health and safety measures required was found to be associated with farmers' status, age, education level, years of pesticide experience, training and to some extent their location. It was also found that the ability of farmers to identify the seven safety symbols on the labels did not mean they were committed to follow these instructions. During the survey, pesticide applicators were frequently observed spraying pesticides without using any type of PPE (Photograph 1, chapter 4) which reflects their unsatisfactory perceptions on the use of these materials and a low level of awareness of the importance of PPE for the health and safety of the personnel responsible for applying the pesticides. The type of spraying machines (high pressure) that farmers used and the method of application (across the rows) used may increase the chance of labourer contamination with pesticide, as was observed in Egypt amongst vegetable growers (Abbassy, 2017 and Cerruto *et al*., 2018). Some of the pesticide poisoning cases being admitted in some of the local hospitals in Oman raises the alarm and should prompt investigations into how such cases happened and how similar problems can be avoided in future. This may require collaboration between MAFWR and Ministry of Health (MoH) and the FA to reduce such poisoning cases due to misuse of pesticides.

4. Can pesticide retailers diagnose the common pests and diseases of the vegetable crops, select the proper pesticide and recommend the proper application rate and PHI and are they aware about the potential risks associated with pesticides?

Previous research has shown an explicit indication of the retailers' roles in farmers' decision making on crop protection issues such as pest and disease diagnosis, pesticide selection and applications (Fan et al., 2015) and advice on health and safety measures (Mubushar et al., 2019). However, retailers or pesticide sellers were found to be the main source of information on pest and disease diagnosis, pesticide selection and application to the farmers. This research introduced a systematic study of the retailers' abilities in diagnosis, pesticide selection and application and health and safety issues associated with pesticide handling and use. Retailers differed in their ability and their competence was affected by their nationality, education level, type of certificate and training. These factors may also affect retailers' willingness to cooperate with governmental and non-governmental associations in the country to improve farmers' pesticide practices by, for example, the introduction of IPM strategies for the different pests and diseases farmers encounter throughout the growing season. In addition, pesticide retailers cannot be expected to help the farming community in introducing new pesticide application technologies to improve the efficiency of current redundant application. There is an urgent need to harmonies the efforts by gathering pesticide retailers, farmers and extension officials in an extensive awareness-raising programmes designed to encourage all stakeholders to adopt the best farming practices including introduction of IPM programmes, new crop protection solutions and technology and reduced dependence on pesticides as the sole or principle crop protection strategy in Oman. This should not only improve crop protection but also reduce the contamination of farmers, food and the environment with pesticides.

Gathering results from chapters (3-6), the comparison between FA, nFA and retailers revealed the higher ability of FA to identify crop problems attacking vegetable crops, selection of the proper pesticides to tackle the problem, using the pesticides according to the label recommendations and identify the possible risks of pesticide handle and use (Table 7.1). Retailers revealed moderate proper practices followed by nFA who seems encounter some difficulties to exercise the proper agriculture practices. However, the results were affected by many factors as discussed in chapters (3-6).

Table 7.1 Comparison between FA (n=40), nFA (n=120) and retailers (n=75) in their response to pests and diseases diagnosis, proper pesticide selection, proper dose rate recommendation, too short pre-harvest interval and identification of potential risks of pesticides.

Variable	FA	nFA	Retailers
	%		
Pest and disease diagnosis	71.4	40.2	50
Proper pesticide selection	78	72.5	64
Proper dose rate	49	29	35
Too short PHI	6.17	27.8	22
Potential risks of pesticide	77.3	26.3	74.3

In conclusion, most of the farmers or growers practicing small-scale farming worldwide and in Oman, whether they were owners, tenants, foremen or workers are, in general, less educated, on low incomes, have had little or no training in diagnosis and pesticides and depend largely on knowledge acquired from parents, friends, neighbours, retailers, or, very occasionally from the extension services. They are practicing agriculture to achieve a livelihood and survive, and assume they are correctly diagnosing crop protection problems, selecting the proper pesticides, applying the right dose of pesticides without complete awareness of adverse health, safety and environmental consequences of incorrect pesticide use. Changing farmers' attitudes and encouraging adoption of better practices needs to be a collaborative and participatory effort involving all stakeholders including farmers, government and public associations. In this way, progress towards greater adoption of optimal farming practices could be achieved. The strategy needs to include training programmes in crop protection (e.g diagnosis and IPM), selecting proper pesticides, and using the right dose with adherence of PHI and understanding safety instructions and using PPE. Moreover, respondents can be categorized into three categories: first, those who can identify problems and know which control strategy or pesticide to use (FA= 69%, nFA= 49%); secondly, those who can identify the problems, but they don't know which control strategy or pesticide to apply (FA= 22%, nFA= 33%); and thirdly, those unable to identify the problems and who do not know which control strategy to use or pesticide to apply (FA= 1%, nFA= 6%). The third group is the most critical one. Diagnosis, pesticide selection and application seem to be relevant to each other. They may increase farmers' variable costs and decrease their gross margins as they experience the consequences of faulty pest and disease diagnoses, choose the wrong pesticides, apply them incorrectly and risk harming themselves, consumers and the environment by unsafe procedures. Designing training programmes that ensure best farming practices may change the shape and content of agriculture in the country towards a better and safer regime for humans and the environment.

Furthermore, and from a wider perspective, training farmers on practices of agriculture systems in general and vegetable farming systems in particular could improve the overall farming process. A systems approach could be used to identify opportunities which might lead to increase farmers' income, reduce cost of inputs, and reduce pollution to humans and the environment. Training farmers on opportunities to improve vegetable production is particularly essential for the small-scale farms where farmers may lack access to information and new technologies on how to improve production, reduce costs, protect the health of farm workers and reduce risk of pesticide residues in produce and in the environment. Training may include all cultivation processes such as land preparation (for specific crops), seed selection (resistant cultivars and best specifications), planting method (for specific crop), how to optimise irrigation and fertilization, pest and disease management, harvesting and crop storage, cleaning, grading and packaging technology and marketing process. Clearly this research has highlighted the urgent need for training in pest and disease diagnosis, pesticide selection and application and proper health and safety measures. Improving the vegetable farming system with optimum use of natural resources would ensure a progressive and more sustainable horticulture industry in the country.

7.3 Recommendations

1. There is a need to introduce holistic and attractive training programmes in crop protection programmes. These should be designed to help FA and nFA farmers and retailers to improve their awareness, knowledge and skills. Separate programmes may be required for non-Arabic speakers, a participatory approach including social scientists as facilitators is recommended to maximise the likelihood of adoption. The curriculum should include

    a. Diagnosis of the pests and diseases that are damaging the economically important crops and cause severe losses to vegetable production;

    b. Pesticide selection and application and health and safety measures;

    c. Diagram showing aspects of pesticide handling that should be included in the training programme as part of a participatory exercise in which participants identify operations where human contamination/environmental pollution/ overdosing/underdosing may arise. Also to identify aspects of pesticide usage that users find the most challenging/dangerous (Figure 7.1).

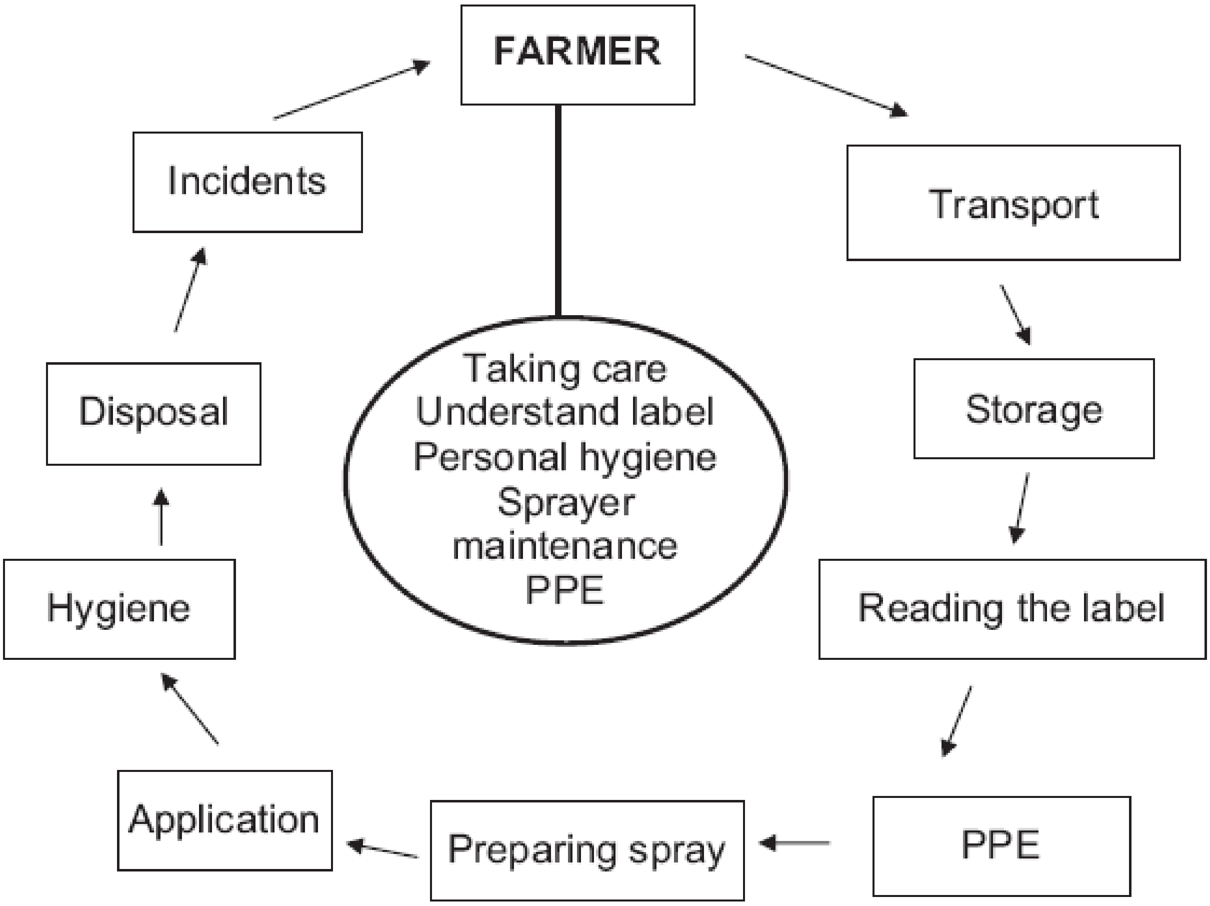


Figure 7.1 Main aspects that could be included in a holistic farmers' training programme (Matthews, 2008).

2. A separate training programme should be set up for crop protection officials and extension services with a view to their establishing reliable, trustworthy communication channels between farmers and the extension service. These personnel should be trained before the farmers and then encouraged to attend the training programmes for farmers in their local area/language. In this way, the farmers will (hopefully) get to know and start to trust the advisers. If possible, the selection process for these personnel should ensure a good prior knowledge of crop protection and of the biology and ecology of the pests and pathogens.
3. Monitoring and evaluation process to explore the extent to which the training programmes recommended above improve the situation. The monitoring and evaluation process may include: the number of training programmes run, assessing proportions of farms (from each area) attending training, changes in practices as a result of such attendance, monitoring pesticide residues of produce before and after attending training programmes and monitoring uptake of advice from extension service.
4. Since diagnosis considered as the key element for proper control strategy, farmers need to obtain proper and trustful advices on diagnoses, select the best control method throughout crop protection cycle and use pesticide in proper way without side effect to human and the environment. The flow chart below (Figure 6.2) is suggested for better farmers' crop protection practices.
5. There is a need to attach a leaflet or brochure of the pesticide label in languages other than Arabic so that the information is can be understood easily by farmers and retailers who do not understand Arabic.
6. Encourage the FA to welcome nFA farmers to join as members to improve their access to technical information on crop protection including diagnosis.
7. Establish and implement integrated pest and disease management programmes to tackle the main pests and diseases (e.g whitefly, spodopteran and early and late blights) attacking vegetable crops for both FA and nFA farmers.
8. Monitor the whole pesticide spraying system including type of machine, pressure, nozzle type, nozzle inclination and size and method of application to

ensures lower use of pesticides with more even spatial distribution and operator safety (Figure 7.2).

9. Apply batch-to-batch pesticide analysis at the port of entry and screening the local manufactures and used pesticides to ensure their quality to fulfil global standards and specifications.
10. There is a need to include basic information on the containers' labels including number of treatments per season, compatibility of mixing with other products and application rate (amount of active ingredient/ha).
11. Enforcement of the pesticide law and its regulations to compel the farmers to provide the PPE and use pesticides in a proper way that ensure efficient application and reduce the abuse that may affect human and environmental health and ensure sustainability of agriculture in Oman.
12. Increase the surveillance and monitoring of pesticide applications and residues in the farms to make sure pesticide users adhere to the laws relating to pesticide use and residues acceptable limits in food.
13. Register and study the cases of pesticide poisoning that are admitted to hospitals and investigate the reasons and discuss the methods to reduce and stop such cases.
14. Establish strong communication channels between MAFWR and retailers to promote the enforcement of pesticide laws and regulations.
15. Establish pesticide training centre or a mobile training unit in the country to provide different types of short and long term courses in different issues related to pesticides and their application.
16. Work towards prohibiting the use of high-pressure hose spraying and adoption of proper spraying machines for large and smaller fields.

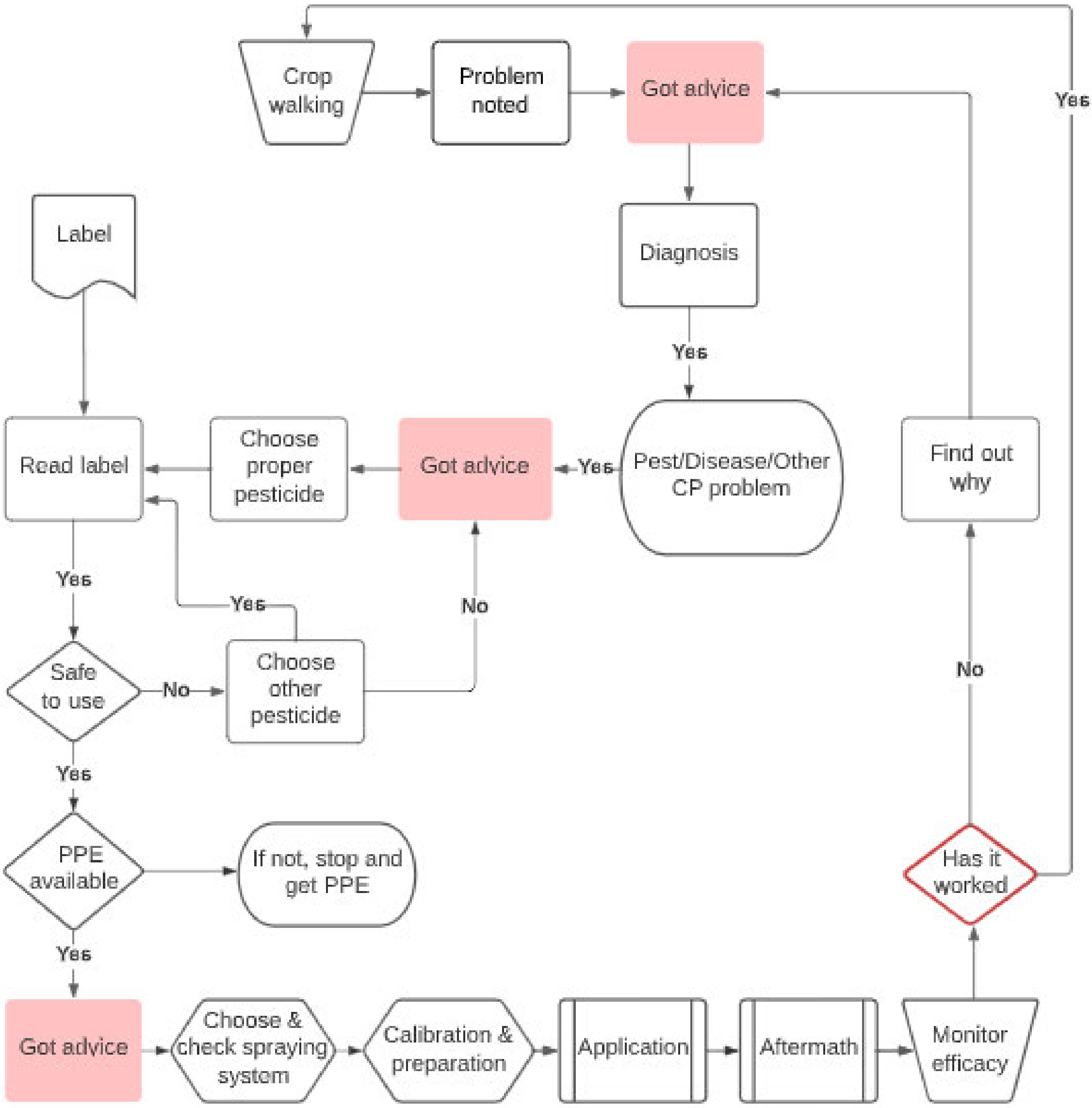


Figure 7.2 Flow chart of advice that farmers need to obtain for proper implementation of a successful pest and disease control strategy.

7.4 Future work

1. Expand the survey of pest and diseases diagnosis, pesticide selection and application to include other vegetables, fruits, field crops and others.

2. Investigate use of pesticides in each particular vegetable crop to control specific pests and diseases and active ingredient used to control that specific problem to expand the view and understand the in-farm pesticide application practices exercised by local farmers and how the problem can be tackled.

3. Screening programme to evaluate the quality of imported pesticides to make sure that all pesticides used in agriculture meet the global specifications in order to eliminate the excessive or underuse of the recommended dose rates.

4. Carry out participatory research with the farmers to explore why they are so reluctant to wear PPE and see how they can be nudged to adopt the use of PPE when handling and spraying pesticides to do that and what are the factors that could help them to follow the health and safety instructions.

Appendices

Appendix 1. Anonymous participation form

My name is Mahmoud Al Nabhani and I am studying for a PhD in Agriculture at the University of Reading in the UK. I am carrying out research on the use of pesticides in Oman as part of my postgraduate programme. The research will be included in my PhD thesis and so will contribute to my degree. As part of the research, I invite you to take part in a short anonymous survey exercise by answering a questionnaire. You have been selected because the target of the research is farmers in your district and we are seeking to include a range of farmers some of whom may be members of Farmers' Associations and some not. Participation is entirely voluntary and you may withdraw from the activity at any time. Should you at any time wish to withdraw any response you made to the questionnaire, you can do so by contacting me (details below) stating the unique participant number at the bottom of this page and the particular response you wish to withdraw. An overall summary of the research results will be available by 31st December 2020. If you would like to have a copy of this please contact me on the contact details below.

Name: Mahmoud Al Nabhani - **Email:** M.M.S.AlNabhani@pgr.reading.ac.uk Tel: +968 99357984

- PhD supervisor:

Dr Alistair Murdoch, University of Reading UK. Email: a.j.murdoch@reading.ac.uk
Professor Mike Deadman, Sultan Qaboos University, Oman. Email: mikedeadman59@gmail.com

By taking part in answering the questionnaire, you have acknowledged that you understand the terms of participation and that you consent to these terms. This application has been reviewed according to the procedures specified by the University of Reading Research Ethics Committee and has been given a favourable ethical opinion for conduct.

Your Unique Participant number is:……………………………………….

Appendix 2. Farm-based Survey Questionnaire

SECTION 1 - GENERAL INFORMATION						
1.1	Name of enumerator (interviewer)	Mahmoud Al Nabhani				
1.2	Date of interview					
1.3	Interviewee's unique participant number					
SECTION 2 - ABOUT THE RESPONDENT						
2.1	What is your status?	Owner	Tenant	Foreman	Worker	Other (specify)
2.2	Who take responsibility on pest diagnosis and selection of pesticides?					
2.3	What is your age?					
2.4	What is your nationality?					
2.5	What is the highest level of education you have completed?	None	Elementary	Grade 7-9	Grade 10-12	Higher education
2.6	How many years of experience in agriculture do you have?					
2.7	How many years of experience in pesticide application do you have?					
2.8	Have you received any training in pesticide application? If NO go to 3	Yes ☐ No ☐				

2.9	Who provided training in pesticide application? Enter code for trainer	If "Other", specify	What training?	When

Government/Commercial	Farmer/Other	Literature/Internet
MAF Extension (MAF)	**FA** Farmers' Association	**LA** Label
C1 Extension (private)	**F5** Owner of farm	**L10** Other (Book/leaflet/brochure)
	F6 Foreman/manager	
C2 Seller/Supplier (Retailer)	**F7** Farm labourer	**L11** Internet (specify)
C3 Seller (Manufacturer Rep.)	**F8** Another farmer	**L12** Social media (eg WhatsApp)
	F9 Other person (specify)	
	F4 Tenant	
Experience:	**E13 Own trial**	**E14 Crop monitoring**
(find out what this means)	**E15 Local/farm practice**	**E16 Common sense/other**

Appendix 2: Continued

SECTION 3 - ABOUT THE FARM

3.1	Is the farm inside a local farmers' association or cooperative?	Yes ☐1	No ☐2		
3.2	If YES, please specify				
3.3	how long has the farm been in this organisation?				
3.4	has the organisation provided any information about pesticides?	yes ☐1	No ☐2		
3.5	If 3.4 is YES, please specify				
3.6	Identify the farm type here	FA	Non-FA managed by owner or direct rent	Non-FA managed through sub-let	Other, please specify
3.7	Wilayat				
3.8	Village				
3.9	Latitude and longitude				
3.10	Farm size (specify units)				
3.11	Is the farm part of a group of farms? If YES, please give details	Yes ☐1	No ☐		
3.12	How many labourers work on the farm?		3.13 How many of these labourers are Omani?		

Appendix 2: Continued

	SECTION 4 - PEST AND DISEASE DIAGNOSIS				
	Can you identify the problems shown in these photographs?				
4.1	Whitefly	Yes ☐1 No ☐2 Not sure☐3	4.7	Melon decline	Yes ☐1 No ☐2 Not sure☐3
4.2	Aphid	Yes ☐1 No ☐2 Not sure☐3	4.8	Powdery mildew	Yes ☐1 No ☐2 Not sure☐3
4.3	Leaf miner	Yes ☐1 No ☐2 Not sure☐3	4.9	Downy mildew	Yes ☐1 No ☐2 Not sure☐3
4.4	Spodoptera n	Yes ☐1 No ☐2 Not sure☐3	4.10	Early blight	Yes ☐1 No ☐2 Not sure☐3
4.5	Thrips	Yes ☐1 No ☐2 Not sure☐3	4.11	Late blight	Yes ☐1 No ☐2 Not sure☐3
4.6	Damping-off	Yes ☐1 No ☐2 Not sure☐3			
4.12	If you do not recognise a pest disease/crop protection problem, who helps you to diagnose the problem? If none of the codes, ____				Enter Code

Appendix 2: Continued

	SECTION 5- PESTICIDES USE AND APPLICATION								
5.1	What are the main crops being grown on the farm?	Rank	Crop	Problem (if known or "insect/disease etc")	Pesticides applied	Dilution rate	Number of treatments usually needed per crop	PHI
			Tomato					
			Pepper					
			Eggplant					
			Melon					

	Appendix 2: Continued	
5.2	How do you decide on the no. of treatments? Details for E and L-codes ______________________________	Enter Code
5.3	How do you decide on the PHI period? Details for E and L-codes ______________________________	Enter Code
5.4	Which crop do you spray most?	
5.5	Which crop do you spray least?	
5.6	If a pesticide does not work, what action do you take?	
5.7	If you are unsure about which pesticide to apply, who would help you to select a pesticide? Details for E and L-codes ______________________________	Enter Code
5.8	Who decides the amount of pesticides to be used?	Enter Code
5.9	How is this amount chosen? Details for E and L-codes	Enter Code
5.10	Who applies pesticides on the farm?	Enter Code
5.11	Has the person who applies pesticides been trained in how to ensure the correct amount is used? If YES, How?	Yes ☐ 1 No ☐ 2 Don't know ☐ 3
5.12	How do you normally apply pesticides?	
5.13	How frequently do you check the condition of your sprayer	

Appendix 2: Continued

SECTION 6 – RISK, HEALTH AND SAFETY

6.1	What possible risks do pesticides have?	None	Soil water	Livestock	Wild animals	Humans

6.2	Have you ever noticed any adverse effects on yourself after applying pesticides?	Never	Rarely	Sometimes	Usually	Always	Would you like to say what they were

6.3	Do you wear any special clothes when applying pesticides?	Never	Rarely	Sometimes	Usually	Always
6.4	What are they?					
6.5	Do you read the safety instructions on pesticides labels before using them?	Never	Rarely	Sometimes	Usually	Always
6.6	Can you list any safety precautions you take when using pesticides other than PPE?					

Look at the picture below.
Do you understand what any of the symbols mean? Tick if correct answer is given

6.7	6.8	6.9	6.10	6.11	6.12	6.13

6.14	Has any organisation ever contacted you to inform you about which pesticides are allowed or not allowed? If yes which (Enter code)	Yes ☐1 No ☐2 Don't know☐3

Appendix 2: Continued				
		SECTION 7 – Pesticides in Store		
7.1	**Which pesticides do you have in the store**			
	Trade name	Active ingredient	Manufacturer/country	Notes
		SECTION 8– GENERAL COMMENTS		
8.1	In your opinion, are there any crop protection problem that are not being controlled by pesticides?			
8.2	Do you have any questions about the survey or crop protection needs?			
8.3	Would you be interested in the results of my research survey? Can you give your contact no.?			

Appendix 3. T-test analysis of farm size (ha), age and years of agriculture experience of FA and nFA respondents.

No.	Variable	FA (n=40)			nFA (n=120)				
		df	Mean	Sum of Square	df	Mean	Sum of Square	T	P
1	Farm size	39	12.9	5094	119	8.74	7501	2.54	0.012
2	Respondents age	39	40.6	4434	119	41.2	14743	0.323	0.747
3	Agriculture experience	39	16	3612	119	17	16826	0.506	0.614

Appendix 4. Mann-Whitney analysis of the education levels of FA and nFA respondents.

Result Details

Sample 1
Sum of ranks: 4018.5
Mean of ranks: 100.46
Expected sum of ranks: 3220
Expected mean of ranks: 80.5
U-value: 1601.5
Expected U-value: 2400

Sample 2
Sum of ranks: 8861.5
Mean of ranks: 73.85
Expected sum of ranks: 9660
Expected mean of ranks: 80.5
U-value: 3198.5
Expected U-value: 2400

Sample 1 & 2 Combined
Sum of ranks: 12880
Mean of ranks: 80.5
Standard Deviation: 253.7716

Result 1 - U-value
The U-value is 1601.5.
Result 2 - Z-ratio
The Z-Score is -3.14456. The p-value is 0.00168. The result is significant at $p < 0.05$.

Appendix 5. Mann-Whitney analysis of the correct diagnosis of the eleven pest and diseases by FA (n=40) and nFA (n=120) respondents.

Result Details

Sample 1

Sum of ranks: 4784.5

Mean of ranks: 119.61

Expected sum of ranks: 3160

Expected mean of ranks: 79

U-value: 715.5

Expected U-value: 2340

Sample 2

Sum of ranks: 7618.5

Mean of ranks: 65.12

Expected sum of ranks: 9243

Expected mean of ranks: 79

U-value: 3964.5

Expected U-value: 2340

Sample 1 & 2 Combined

Sum of ranks: 12403

Mean of ranks: 79

Standard Deviation: 248.2338

Result 1 - U-value

The U-value is 715.5

Result 2 – Z-ratio

The z-score is -6.54222. The p-value is < 0.00001.

The result is significant at $p < 0.05$

Appendix 6. Kruskal-Wallis analyses of the effects of FA (n=40) and nFA (n=120) respondents' status, age, education level, years of pesticide experience, training, location and farm size on the ability of respondents to identify pests and diseases.

	Summary statistics on Ranks and Test Results										
Variable*	Rank averages										H, P
Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foreman	FA Worker				
	131	119	106	102	56.9	61.4	43.7				62.9, < 0.001
Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69		
	119	104	130	116	47.1	64.9	68.5	69.5	101		44.9, < 0.001
Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		
	90.5	120	132	133	48.6	60.2	71.1	67.6	105		60.6, < 0.001
Agriculture experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	
	118	126	121	126	49.7	69.9	69.5	81	82.6	125	55.8, < 0.001
Training	FA with training	FA without training	nFA with training	nFA without training							
	121	122	120	65.3							47.8, < 0.001

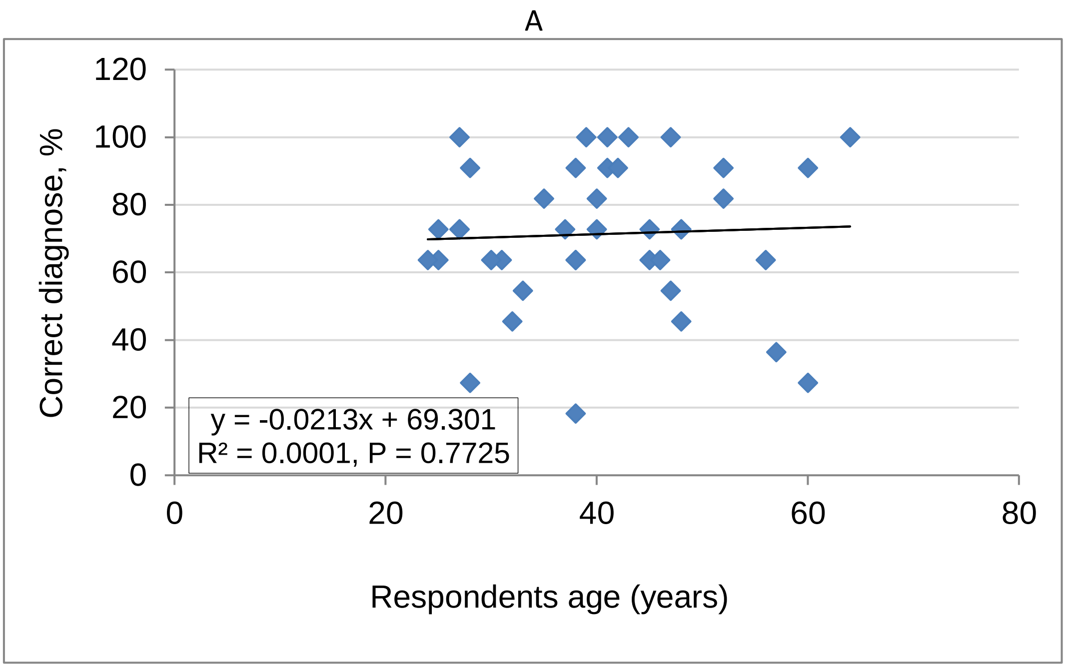
Appendix 6: Continued															H, P
Location	FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	48.9, < 0.001
	116	103	58.5	50.9	63.5	42.8	52.4	59.6	45.4	52.9	119	89	54.7	80.4	
Farm size	FA 0-4.9	FA 5-9.9	FA 10-14.9	FA 25-29.9	FA 30-34.9	nFA 0-4.9	nFA 5-9.9	nFA 10-4.9	nFA 15-9.9	nFA 20-24.9	nFA 25-29.9				
	106	115	130	108	138	55.4	72.2	74.4	82.5	58.5	87.5				46, < 0.001
Source of diagnosis advice	FA MAFWR	FA Retailers	FA Another farmer	nFA MAFWR	nFA Retailers	nFA Another farmer	nFA FA								
	100	119	98.7	101	60.1	67.9	63.1								43, < 0.001

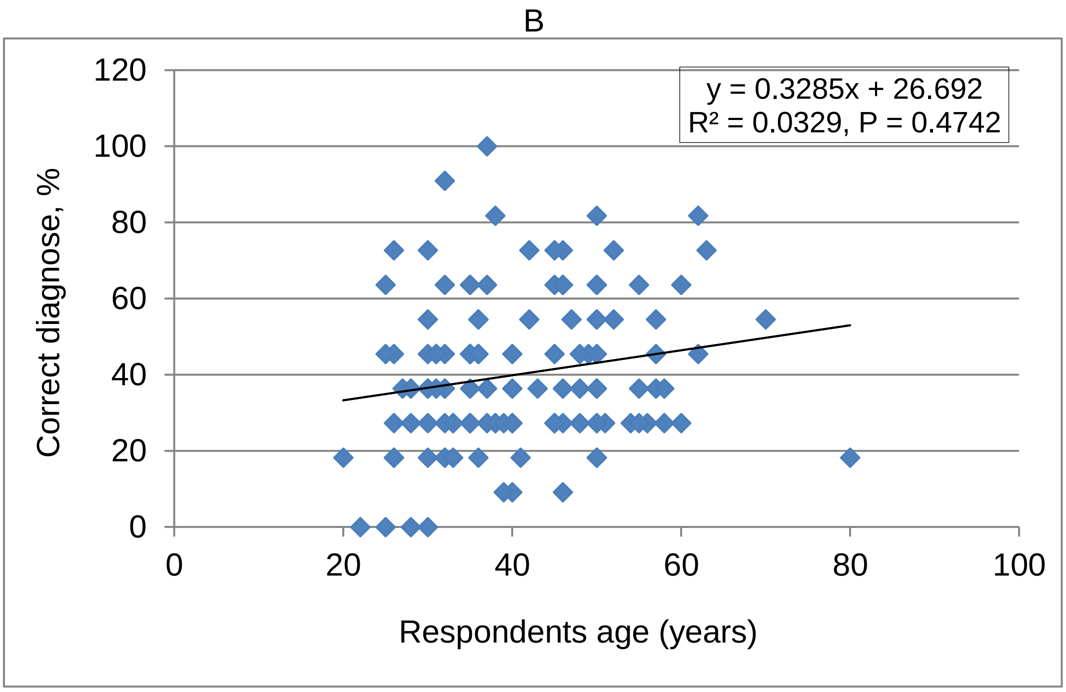
Appendix 6: Continued					
Pairwise Comparisons					
			Abs Mean		Statistical
	Factor 1	Factor 2	Rank Diff.	Threshold	Significance
Status	FA (Owner)	nFA (Owner)	29.8	45	no
	FA (Tenant)	nFA (Tenant)	62.2	40.3	yes
	FA (Forman)	nFA (Foreman)	44.6	70	no
Age	FA (20-29)	nFA (20-29)	72.3	64.9	yes
	FA (30-39)	nFA (30-39)	39.0	56.2	no
	FA (40-49)	nFA (40-49)	61.2	50.2	yes
	FA (50-59)	nFA (50-59)	46.6	78.4	no
	FA (60-69)	nFA (60-69)	10.8	107	no
Education level	FA (Elementary)	nFA (Elementary)	30.3	69.9	no
	FA (Grade 7-9)	nFA (Grade 7-9)	49.1	49.6	no
	FA (Grade 10-12)	nFA (Grade 10-12)	64.1	56.1	yes
	FA (Higher)	nFA (Higher)	27.9	63.9	no
Agriculture experience	FA (1-9)	nFA (1-9)	68.6	47.4	yes
	FA (10-19)	nFA (10-19)	55.8	52.4	yes
	FA (20-29)	nFA (20-29)	51.8	57.9	no
	FA (30-39)	nFA (30-39)	44.5	73.7	no
Training	FA (with training)	nFA (with training)	1.43	89.3	no
	FA (without training)	nFA (without training)	56.9	23.6	yes
Location	FA (Al Musanah)	nFA (Al-Musanah)	65.3	65.1	yes
	FA (A’Suwaiq)	nFA (A’Suwaiq)	39.4	40.5	no

Appendix 6: Continued

			Abs Mean Rank Diff.	Threshold	Statistical Significance
	Factor 1	Factor 2			
Farm size	FA (0-4.9)	nFA (0-4.9)	50.6	54	no
	FA (5-9.9)	nFA (5-9.9)	42.7	46	no
	FA (10-14.9)	nFA (10-14.9)	55.9	75.3	no
	FA (25-29.9)	nFA (25-29.9)	20	122	no
Source of diagnosis advice	FA (MAFWR)	nFA (MAFWR)	1.44	83.6	no
	FA (Retailers)	nFA (Retailers)	58.5	31	yes
	FA (Another farmer)	nFA (Another farmer)	30.8	74.1	no

Appendix 7. Pearson correlation analysis of diagnosis of crop problems and respondents' age for A) FA (n=40) and B) nFA (n=120) respondents.

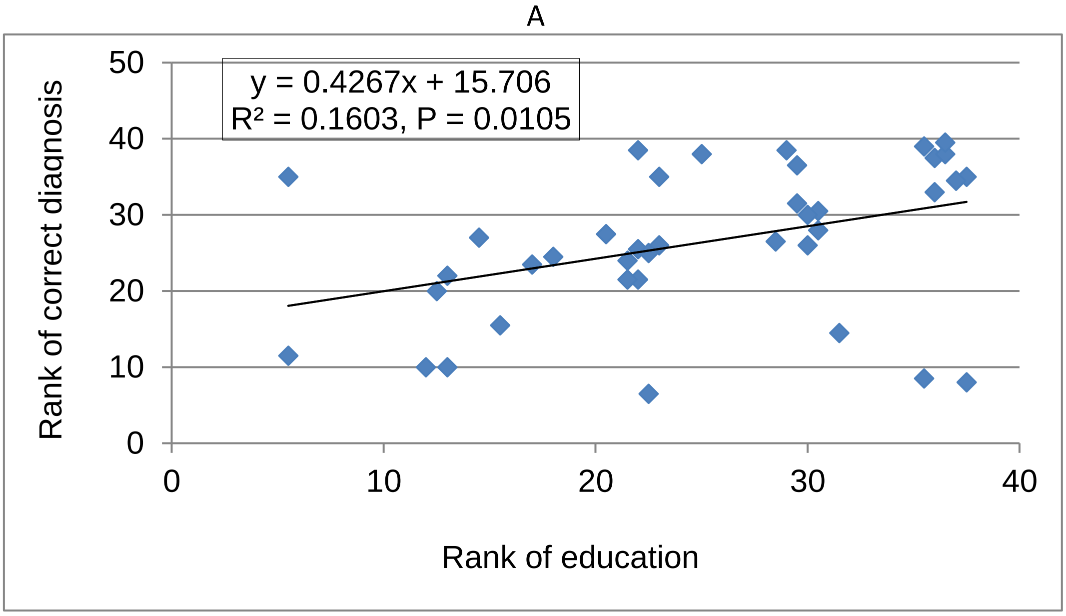


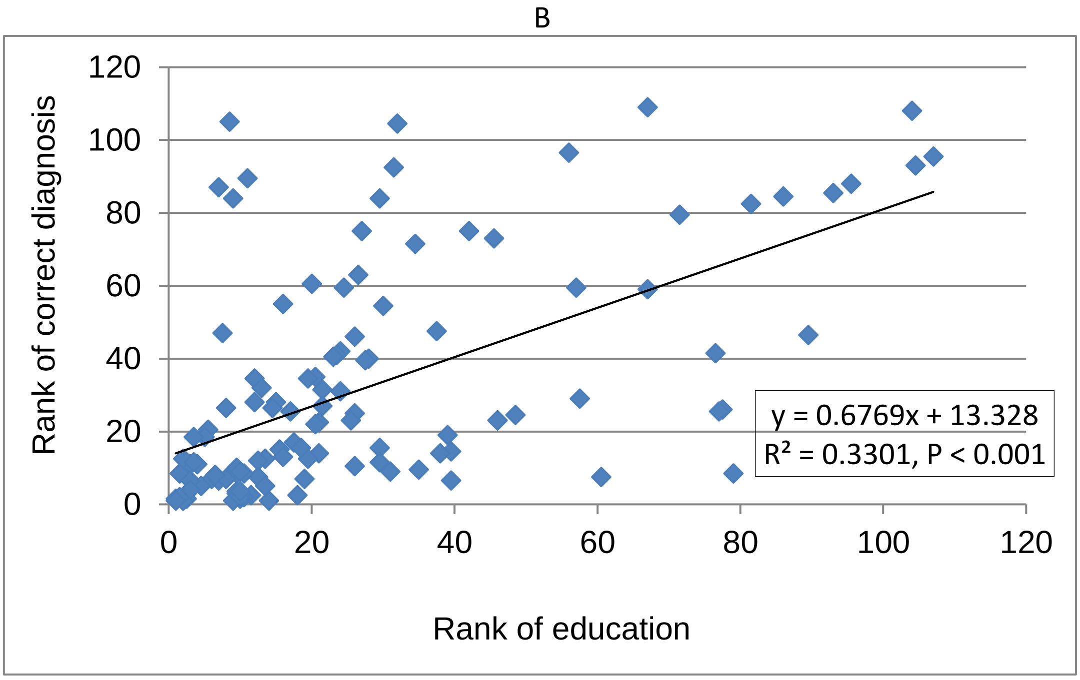


Appendix 8. Pearson correlation p-value of FA (n=40) and nFA (n=120) respondents' ages versus correct diagnosis.

	FA	nFA
Coefficient (r_s):	0.047	0.181
N:	40	120
T statistic:	0.291	2.00
DF:	38	118
P value:	0.773	0.047

Appendix 9. Pearson correlation analysis of diagnosis of crop problems and respondents' age for A) FA (n=40) and B) nFA (n=120) respondents.



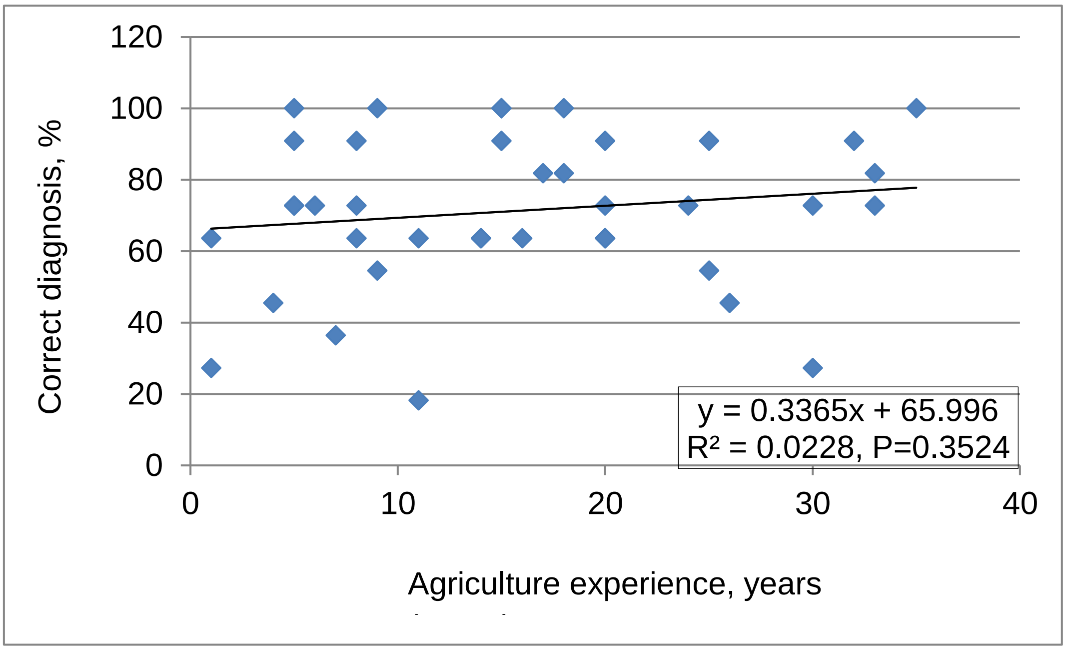


Appendix 10. Pearson correlation p-value of FA (n=40) and nFA (n=120) respondents' ages (years) versus correct diagnosis (%).

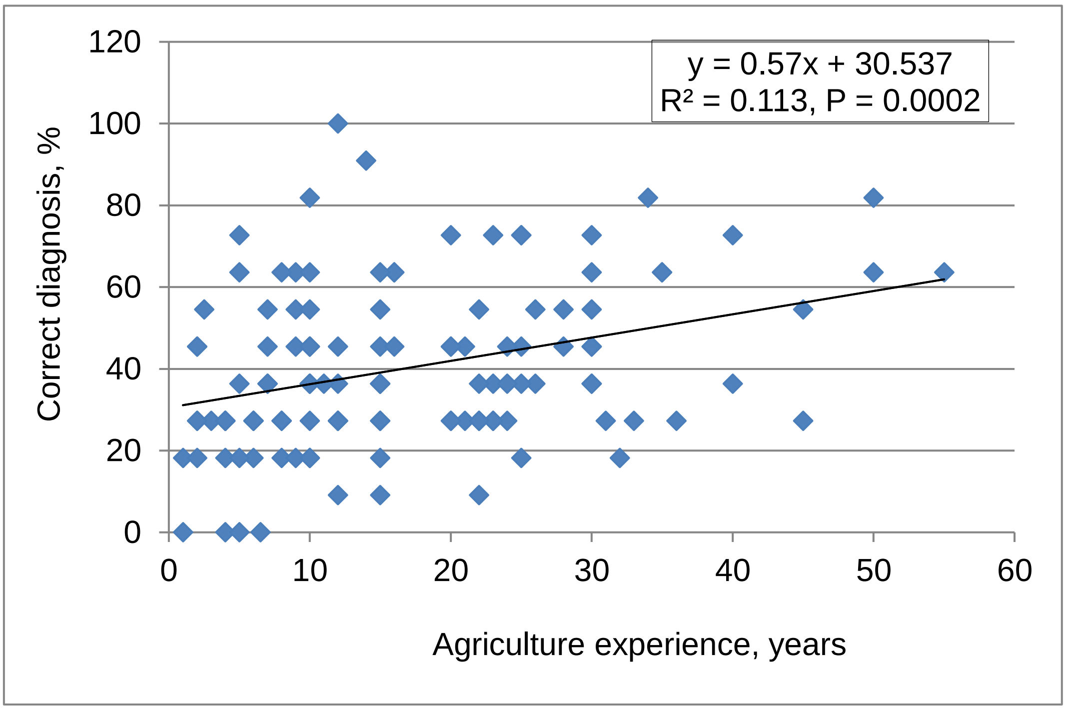
	FA	nFA
Coefficient (r_s):	0.400	0.575
N:	40	120
T statistic:	2.69	7.63
SD:	38	118
P value:	0.011	<0.001

Appendix 11. Pearson correlation analysis of diagnosis of crop problems and respondents' agriculture experience for A) FA (n=40) and B) nFA (n=120) respondents.

A



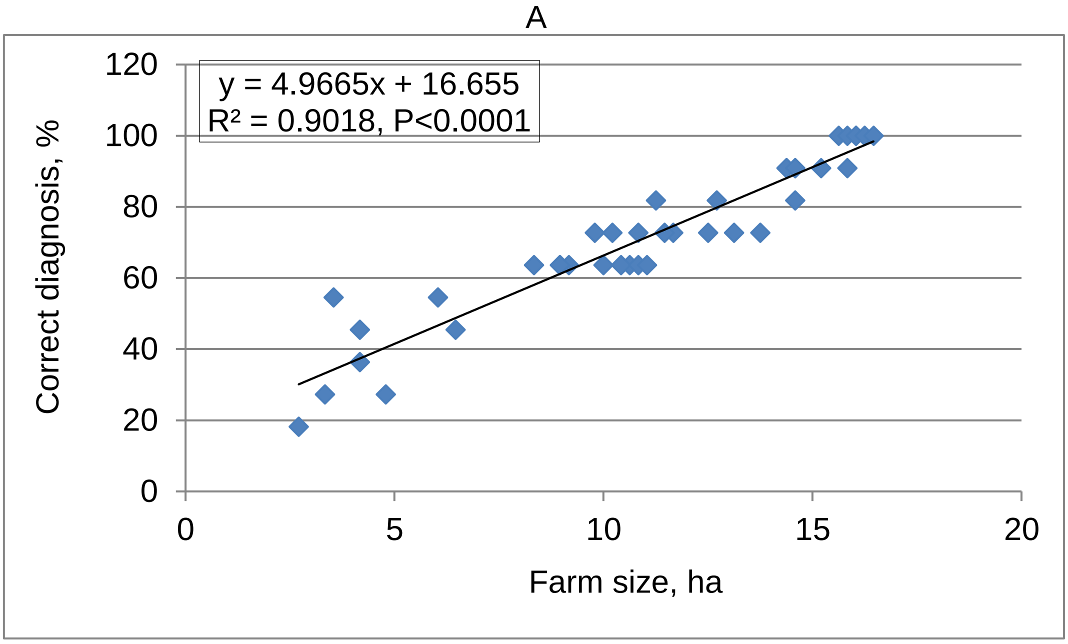
B

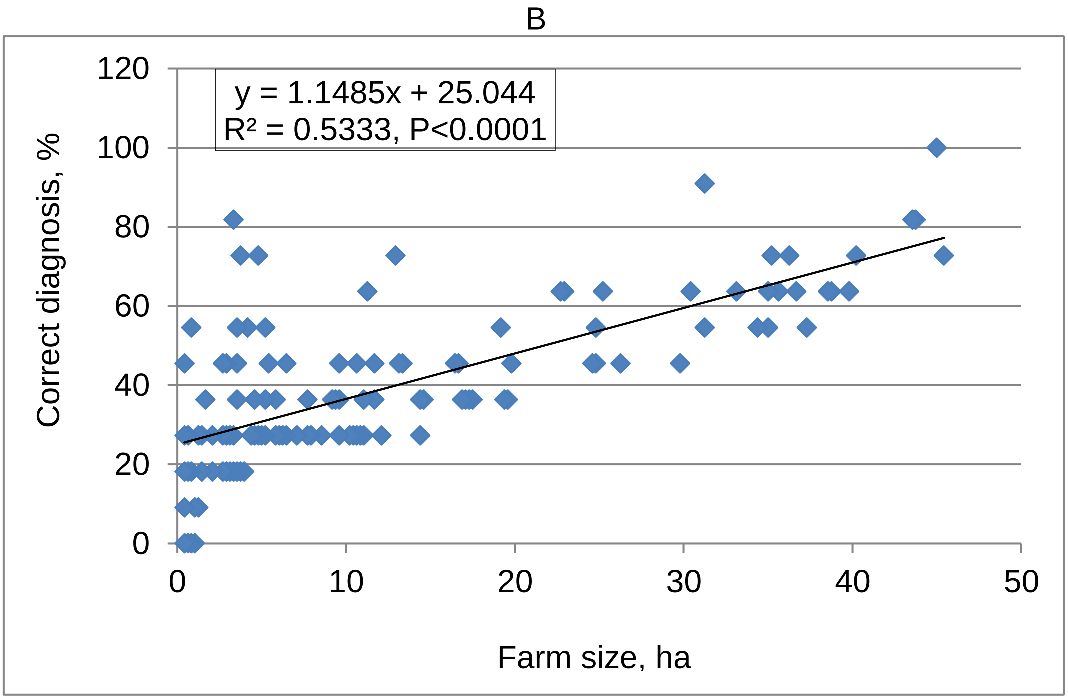


Appendix 12. Pearson correlation p-value of FA (n=40) and nFA (n=120) respondents' agriculture experience (years) versus correct diagnosis (%).

	FA	nFA
Coefficient (r_s):	0.151	0.336
N:	40	120
T statistic:	0.942	3.88
DF:	38	118
P value:	0.352	<0.001

Appendix 13. Pearson correlation between diagnosis of crop problems and farm size (ha) for FA (n=40) and nFA (n=120) respondents.





Appendix 14. Kruskal-Wallis analysis of the percentages of pests and diseases found in the FA (n=40) and nFA (n=117) respondent's farms.

	FA Whitefly	FA Leaf miner	FA Spodop-teran	FA Thrips	FA Melon decline	FA Powdery mildew	FA Early blight	FA Late blight	nFA Whitefly	nFA Aphid	nFA Leaf miner	nFA Spodop-teran	nFA Thrips	nFA Melon decline	nFA Downy mildew	nFA Early blight	nFA Late blight	H, P
Summary Statistics on Ranks & Test Results																		
Rank Average:	259	47.8	206	118	110	113	182	163	331	259	201	305	161	146	137	187	229	145, <0.001

Pairwise Comparisons

Factor 1	Factor 2	Abs Mean Rank Diff.	Threshold	Statistical Significance
FA (Whitefly)	nFA (Whitefly)	72	95.3	no
FA (Leaf miner)	nFA (Leaf miner)	153	217	no
FA (Spodopteran)	nFA (Spodopteran)	99	112	no
FA (Thrips)	nFA (Thrips)	43.3	158	no
FA (Melon decline)	nFA (Melon decline)	36.3	188	no
FA (Early blight)	nFA (Early blight)	4.78	130	no
FA (Late blight)	nFA (Late blight)	66	162	no

* Pests or diseases with less than three observations were excluded.

Appendix 15. Mann-Whitney and Kruskal-Wallis analyses of proper selection of FA (n=40) and nFA (n=117) respondents and the effect of respondent's status, age, education levels, pesticides experience and training in response to ability to select the proper pesticide.

Variable	Summary statistics on Ranks and Test Results										H/U, P
	Rank averages										
Pesticide Selection	FA (Proper selection)					nFA (Proper selection)					
	83.9					77.3					2145, NS
Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker				
	81	88.6	91.5	52.3	93.3	68.5	116.3				20, 0.003
Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	72	92.1	91.7	80.8	80.5	61.9	87.2	70.5	76.8	41.3	10, NS
Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		
	89.9	82.4	87.4	85.3	60.3	74.1	74.9	94.1	63.4		10, NS
Pesticides Experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49		
	84.5	82.8	97.5	72.8	81.9	74.8	70.4	73.3	59.5		4, NS

Table 15: Continued												
Training	FA (with training)		FA (without training)	nFA (with training)			nFA (without training)					
	82.4		86.5	62.3			77					2, NS
Location	FA Al-Musanah		FA A'Suwaiq			nFA Al- Musanah		nFA A'Suwaiq				
	71.2		76.3			70.9		87.1				21, NS
Farm size	FA 0-4.9	FA 5-9.9	FA 10-14.9	FA 25-29.9	FA 30-4.9	nFA 0-4.9	nFA 5-9.9	nFA 10-14.9	nFA 15-19.9	nFA 20-24.9	nFA 25-29.9	
	92	74.4	90.7	64.7	96.3	72.6	69.7	85	78.8	65.1	67.4	5, NS

Appendix 15: Continued

Pairwise Comparisons

Factor 1	Factor 2	Abs Mean Rank Diff.	Threshold	Statistical Significance
FA (Owner)	nFA (Owner)	28.7	45.4	no
FA (Tenant)	nFA (Tenant)	4.7	39.1	no
FA (Foremen)	nFA (Foremen)	23	59.8	no
nFA (Owner)	nFA (Tenant)	41.1	36.5	yes
nFA (Owner)	nFA (Foremen)	16.2	35.6	no
nFA (Owner)	nFA (Worker)	64.1	63.6	yes
nFA (Tenant)	nFA (Foremen)	24.8	29.4	no
nFA (Tenant)	nFA (Worker)	23	60.4	no
nFA (Foremen)	nFA (Worker)	47.8	59.8	no

Appendix 16. Frequency and percentage of the pesticides selected by FA (n=40) and nFA (n=117) respondents to control the common eleven pests and diseases attacking their vegetable crops.

Pest/disease	A.I	All farms		FA		nFA	
		N	%	N	%	N	%
Whitefly	Thiamethoxam	17	95.5	2	5	15	12.8
	Malathion	8	47.9	6	15	2	1.7
	Thiacloprid	8	53	5	12.5	3	2.6
	Dinotefuran	6	59.4	3	7.5	3	2.6
	Pyriproxyfen	5	54.3	3	7.5	2	1.7
	Oxymatrine	8	94.1	1	2.5	7	6
	Pirimiphos-methyl	2	58.8	1	2.5	1	0.9
	Abamectin	2	58.8	1	2.5	1	0.9
	Buprofezin	1	2.5	1	2.5	0	0
	Fenpyroximate	2	1.7	0	0	2	1.7
Spodopteran	Lufenuron	15	84.3	3	7.5	12	10.3
	Indoxicarb	7	6	0	0	7	6
	Esfenvalerate	4	78.4	1	2.5	3	2.6
	Methomyl	4	78.4	1	2.5	3	2.6
	Fenitrothion	3	7.5	3	7.5	0	0
	Malathion	3	2.6	0	0	3	2.6
	Etofenprox	1	0.9	0	0	1	0.9
Leaf miner	Emamectin benzoate	2	1.7	0	0	2	1.7
	Chlorantraniliprole	1	0.9	0	0	1	0.9
	Deltamethrin	1	0.9	0	0	1	0.9
	Acetamiprid	1	0.9	0	0	1	0.9
Aphid	Malathion	4	3.4	0	0	4	3.4
	Deltamethrin	3	2.6	0	0	3	2.6
	Thiamethoxam	2	1.7	0	0	2	1.7
Thrips	Acrinathrin, Abamectin	3	7.5	3	7.5	0	0
	Abamectin	2	5	2	5	0	0
	Dinotefuran	1	2.5	1	2.5	0	0
	Thiamethoxam	1	0.9	0	0	1	0.9
Melon decline	Hymexazol	6	71.4	2	5	4	3.4
	Carbendazim	4	78.4	1	2.5	3	2.6
	Thiophenate methyl	2	1.7	0	0	2	1.7
	Metalaxyl, Copper oxychloride	1	2.5	1	2.5	0	0
	Propamocarb	1	0.9	0	0	1	0.9
Powdery mildew	Flutriafol	1	2.5	1	2.5	0	0
	Propenib	1	0.9	0	0	1	0.9

Appendix 16: Continued							
Pest/disease	A.I	All farms		FA		nFA	
		N	%	N	%	N	%
Downy mildew	Fosetyl alumenium	1	2.5	1	2.5	0	0
	Metalaxyl	1	0.9	0	0	1	0.9
	Propamocarb	1	0.9	0	0	1	0.9
Early blight	Iprodione	11	45.5	9	22.5	2	1.7
	Difenoconazole	9	51.1	6	15	3	2.6
	Carbendazim	7	44	6	15	1	0.9
	Difenoconazole, Azoxystrobin	8	6.8	0	0	8	6.8
	Metalaxyl	3	2.6	0	0	3	2.6
	Copper hydroxide	1	2.5	1	2.5	0	0
	Propineb	1	2.5	1	2.5	0	0
	Trifloxystrobin	1	2.5	1	2.5	0	0
	Azoxystrobin	2	1.7	0	0	2	1.7
	Cymoxanil, Copper oxychloride	2	1.7	0	0	2	1.7
Late blight	Propamocarb	6	44.8	5	12.5	1	0.9
	Metalaxyl, Copper oxychloride	5	12.5	5	12.5	0	0
	Mandipropamid, Difenconazole	4	10	4	10	0	0
	Cymoxanil, Copper oxychloride	5	54.3	3	7.5	2	1.7
	Metalaxyl	2	5	2	5	0	0
	Fosetyl alumenium	1	2.5	1	2.5	0	0
	Azoxystrobin	1	0.9	0	0	1	0.9
	Carbendazim	1	0.9	0	0	1	0.9

Appendix 17. Mann-Whitney and Kruskal-Wallis analysis of FA (n=40) and nFA (n=120) respondents to the correct pesticides dose rates recommendations and the effect of respondent's status, age, education levels, pesticides experience, training, location and farm size on their responses.

Summary statistics on Ranks and Test Results											
Variable	Rank averages										H/U, P
Dose rate	FA (correct dose rate)				nFA (correct dose rate)						
	99.7				71.9						1511, < 0.001
Status	FA Owner	FA Tenant	FA Foremen		nFA Owner	nFA Tenant	nFA Foremen		nFA Worker		
	95.6	108	87.5		70.6	80	62		101		19, 0.004
Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	82	93.5	103	128	105	67.7	71.3	71.1	68.6	101	16.9, 0.049
Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		
	77.6	99.8	112	91.3	56.5	70.2	72.3	85.9	67.1		17.8, 0.023
Pesticides experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49		
	101	87.7	112	110	68.7	73.3	69.5	78.9	105		15.6, 0.049

Appendix 17: Continued					H/U, P
Training	FA (with training)	FA (without training)	nFA (with training)	nFA (without training)	
	123	96.5	86	71.5	13.4, 0.004
Location	FA Al-Musanah	FA A'Suwaiq	nFA Al- Musanah	nFA A'Suwaiq	
	91.1	93.7	68	83.9	24.2, 0.029

Farm size	FA 0-4.9	FA 5-9.9	FA 10-14.9	FA 25-29.9	FA 30-34.9	nFA 0-4.9	nFA 5-9.9	nFA 10-14.9	nFA 15-19.9	nFA 20-24.9	nFA 25-29.9	
	68.1	98.2	113	110	117	64.5	73.4	60.6	98	77.4	81.8	20.4, 0.026

* Variables with than three records were excluded.

Appendix 18. Kruskal-Wallis analysis of the effect of FA (n=40) and nFA (n=117) respondent's status, age, education levels, pesticides experience, training, location and farm size in response to their ability to recommend proper PHI.

Summary statistics on Ranks and Test Results											
Variable*	Rank averages										H/U, P
PHI	FA correct PHI					nFA correct PHI					
	102					71.2					1425, < 0.001
Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker				
	107	104	82.8	69.6	71.2	74.4	51.2				18.8, 0.004
Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	109	81.3	110	128	70.8	60.3	74.1	66.2	81.3	40	27.7, 0.001
Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher		
	87.8	105	97.6	110	79.9	69.4	67.4	68.3	63.5		19.7, 0.012
Pesticides Exp.	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49		
	97.9	95.1	115	112	68.6	69.1	84.1	69.3	61.8		19.4, 0.013
Training	FA with training	FA without training	nFA with training	nFA without training							
	115	100	61.8	71.4							16.4, 0.001

Appendix 18: Continued

	Rank averages											H, P
Location	FA Al- Musanah		FA A’Suwaiq		nFA Al-Musanah		nFA A’Suwaiq					
	95.9		85.4		64.8		73.5					16.1, 0.245
Farm size	FA 0-4.9	FA 5-9.9	FA 10-14.9	FA 25-29.9	FA 30-34.9	nFA 0-4.9	nFA 5-9.9	nFA 10-14.9	nFA 15-19.9	nFA 20-24.9	nFA 25-29.9	
	89.4	99.1	87.8	129	88.5	62.4	71.7	83.3	64.4	77.3	55.9	19.8, 0.032

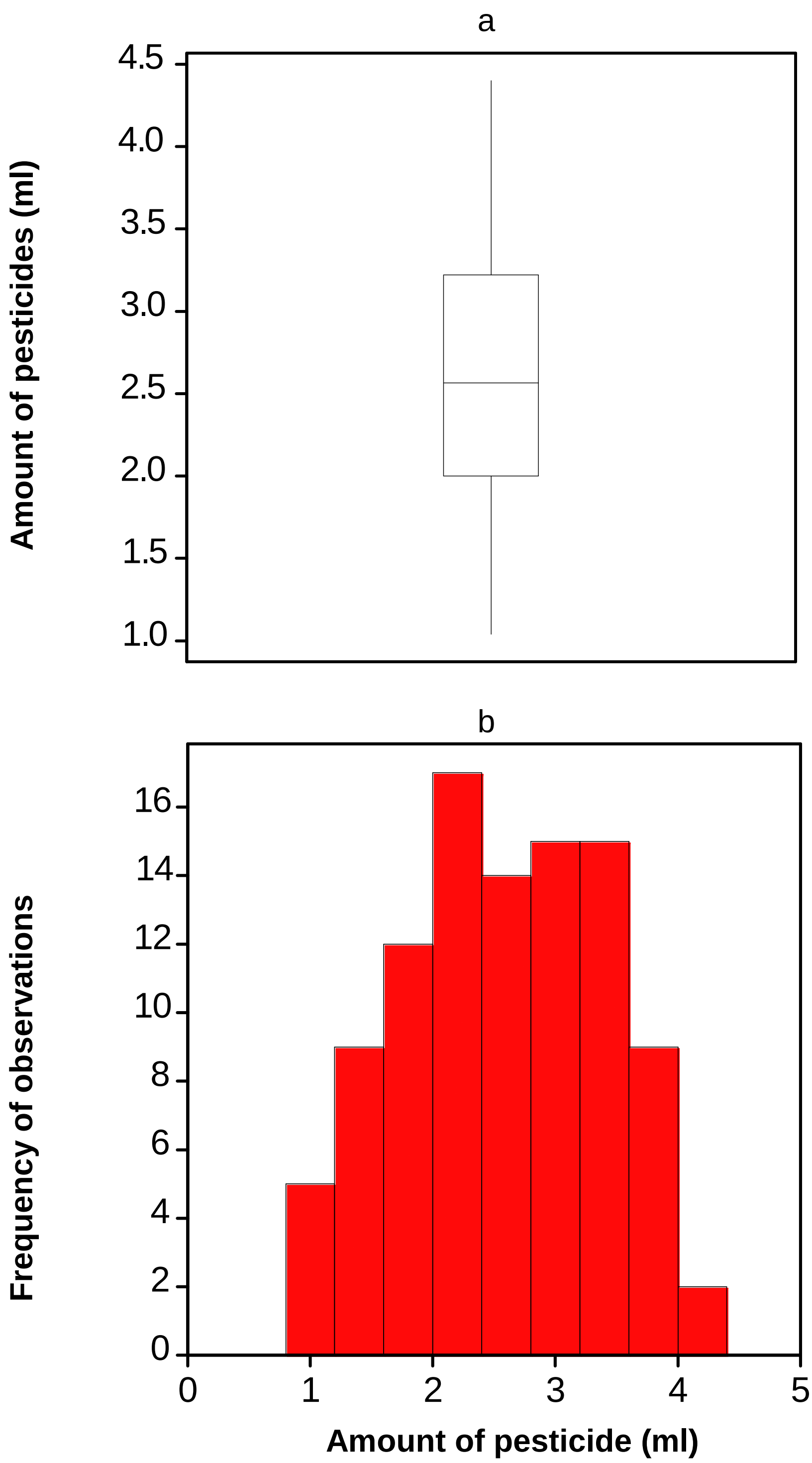
Appendix 19. Focus group discussion of FA farmers (n=13) to gauge their perceptions on pesticide applications and resistance problems.

Question	Answers	Number of respondents
1. Do you mix the pesticides?	- All participants mix more than one pesticide together, but they are not mixing the same active ingredient of different brand names of pesticides. For instance, they mix insecticide with fungicide or insecticide with plant stimulant, and they revealed that they mix insecticides (of different active ingredients) together or fungicides together. - Before they mix pesticides, first they ask another farmer to obtain application and efficacy experience on same practice and/or they may ask the supplier for more information to avoid any damage of mixing to their plants. - They check the ability for mixing from the labels, since some of the pesticides may burn the plants at elevated temperatures. - In some cases, they may mix insecticide with fungicide and acaricide, but they do that after doing some trials in small scale. So, they mix first then check residues and plant health. If all things went well, they keep doing the same mixture for next seasons. - In greenhouses or shade house, especially for sweet pepper cultivation, during the harvest, it is very difficult to spray an individual pesticide for each problem and in short periods. In such cases, mixing more than one type of pesticides will control many problems at once. They also check the residues in the private laboratory to make sure that the pesticides mixture does not increase the residues level in the edible parts (e.g fruits). - In open fields, mixing more than one pesticide is very rare but in the greenhouses and shade houses, mixing is very common because in open fields the season is very short.	13

Appendix 19: Continued		
Question	Answers	Number of respondents
2. Are there any pesticides that are no longer effective?	- Yes, some pesticides are no longer as effective as they used to be before so the farmers increased the concentration of a.i to get better results. The farmers thought that some of the insects develop a sort of resistance against some of the pesticides. - For example, they claimed that Calypso (a.i Thiacloprid) insecticide is no longer effective against whitefly on tomato, cucumber and eggplants and other vegetables. The farmers believe that the whitefly evolved resistance against some of the insecticides but other farmers said they Calypso is still effective for whitefly on tomato and sweetmelon in fields located in the southern part of Oman (Dhofar district). - Some FA members believed that increasing the doses by farmers will increase the problem of resistance. - Another example for pesticide resistance is Vertemic (Abamectin 1.8% EC). Some FA members revealed that they were using the same pesticide for ten years against mites on squash and while it used to be very efficient, it is no longer effective. Other farmers indicated that they had severe infestations of mites on cucumber and when they sprayed Vertemic they got very good results. They disclosed that when they use generic or me-too products they did not get good control but when they changed to genuine products they got better results. - FA members disclosed that new active ingredients were more effective than old ones.	3
3. If chemical does not work, what action you take?	- FA members revealed that they select another pesticide. - Some problems such as wilt were not controlled by using of all types of fungicides. Another example was early and late blights on tomato. All fungicides used were unable to control the problem.	13

Appendix 19: Continued		
Question	Answers	Number of respondents
4. In your opinion, are there any crop protection problems that were not being controlled by pesticides?	- Late blight on tomato. - Wilt on cucurbits. - Cucurbit fruit fly.	12 1 5
5. Are you using resistant cultivars?	- Yes, FA members were using resistant cultivars, but they revealed that resistant cultivars were not sufficient to control wilt on tomato and cucurbits. Results were not convincing the farmers.	6
6. Are there any problems that you do not know how to control?	- Wilt problems on tomato.	8

Appendix 20. Box-plot (a) and histogram (b) for the amount of pesticides spatially deposited in 100 samples at Al Bedi field (Al Musanah).



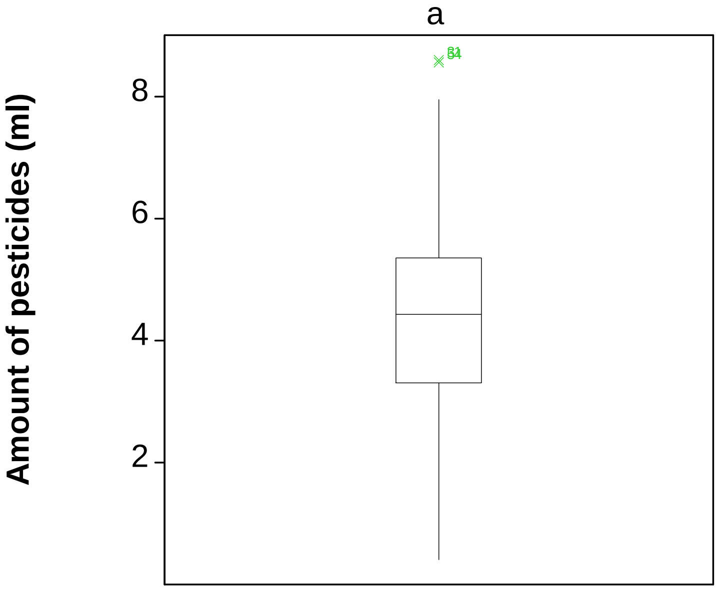
Appendix 21. Summary statistics for the amount of pesticide and summary of analysis of the variogram model for Al Bedi field (Al Musanah).

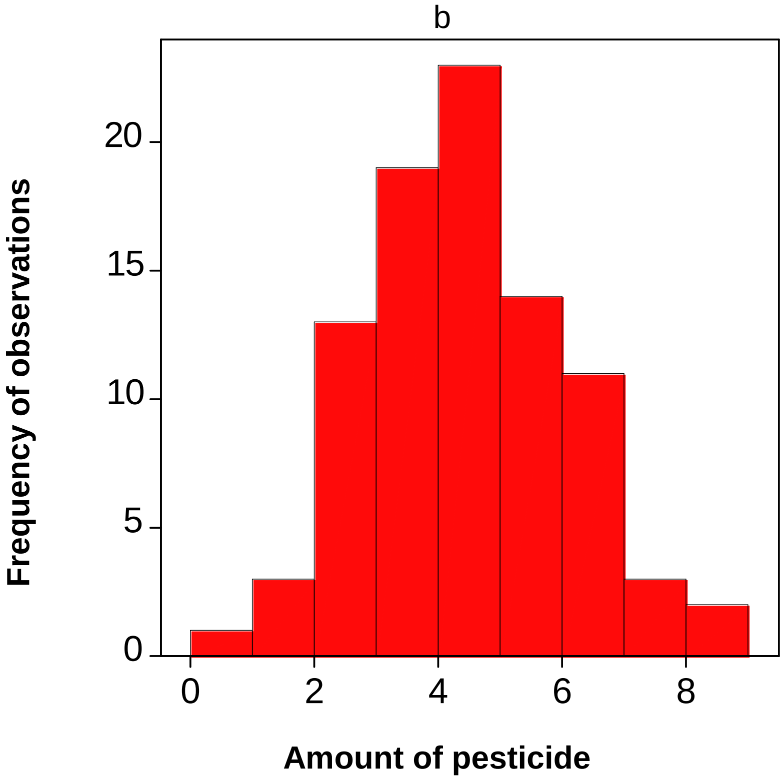
Summary statistics for amount of pesticide	
Number of values	98
Mean	2.59
Median	2.57
Minimum	1.04
Maximum	4.4
Standard deviation	0.819
Variance	0.670
Coefficient of variation, %	31.6
Skewness	0.027

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.
Regression	2	6.17	3.09	2.73
Residual	4	4.52	1.13	
Total	6	10.7	4.22	

Appendix 22. Box-plot (a) and histogram (b) for the amount of pesticides spatially deposited in 100 samples at A'Salam field (Barka).





Appendix 23. Summary statistics for the amount of pesticide and summary of analysis of the variogram model for A'Salam field (Barka).

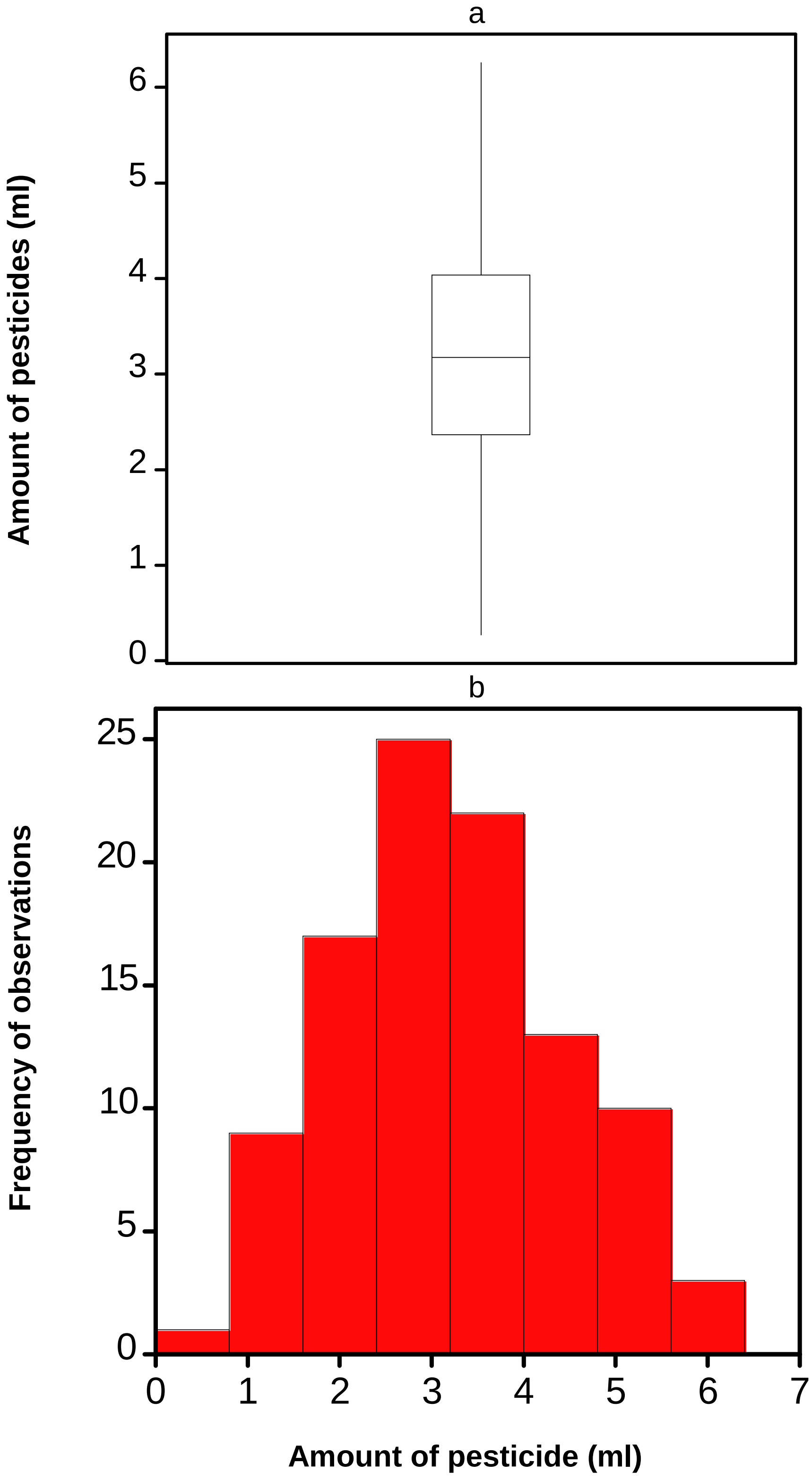
Summary statistics for amount of pesticide

Number of values	89
Mean	4.44
Median	4.43
Minimum	0.41
Maximum	8.60
Standard deviation	1.63
Variance	2.67
Coefficient of variation, %	36.8
Skewness	0.292

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.
Regression	2	26.7	13.3	1.79
Residual	2	14.9	7.46	
Total	4	41.6	10.4	

Appendix 24. Box-plot (a) and histogram (b) for the amount of pesticides spatially deposited in 100 samples at Al Qurayhah filed.



Appendix 25. Summary statistics for the amount of pesticide and summary of analysis of the variogram model for Al Qurayhah field.

Summary statistics for amount of pesticide	
Number of values	100
Mean	3.22
Median	3.18
Minimum	0.27
Maximum	6.26
Standard deviation	1.24
Variance	1.55
Coefficient of variation, %	38.7
Skewness	0.193

Summary of analysis of the variogram (Cubic model)

Source	d.f.	s.s.	m.s.	v.r.
Regression	2	6.44	3.22	1.03
Residual	5	15.7	3.14	
Total	7	22.1	3.16	

Appendix 26. Mann-Whitney and Kruskal-Wallis analysis of FA (n=40) and nFA (n=120) respondents' responses to awareness of pesticide potential risks and the effect of status, age, education levels, pesticides experience, training and location on respondents' responses.

Summary statistics on Ranks and Test Results

Variable*	Rank averages														H/U, P
Risks	FA	nFA													
	120	67.3													819, < 0.001
Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker								
	126	113	124	133	60.3	56.6	38								87.9, < 0.001
Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69					
	115	115	121	121	120	64.1	61.7	74.5	61.2	97.9					48, < 0.001
Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher						
	117	108	121	134	63.2	58.9	72.7	58.4	110						59.4, < 0.001
Pesticides experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49						
	123	117	118	122	61.9	65.5	69.9	88.6	93.5						48.9, < 0.001
Training	FA with training	FA without training	nFA with training	nFA without training											
	141	117	96.8	66.6											46.9, < 0.001
Location	FA Al Musanah	FA A'Suwaiq	nFA Barka	nFA Al Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al Kamel	
	108	110	55.6	48.2	42.9	36	60.4	60.5	45.2	76.4	127	119	115	96.1	80.9, < 0.001

Appendix 26: Continued					
Pairwise Comparisons					
			Abs Mean		Statistical
	Factor 1	Factor 2	Rank Diff.	Threshold	Significance
Status	FA (Owner)	nFA (Owner)	6.25	49.8	no
	FA (Tenant)	nFA (Tenant)	53.0	38.7	yes
	FA (Forman)	nFA (Foreman)	67.2	61.0	yes
Age	FA (20-29)	nFA (20-29)	51.2	66.1	no
	FA (30-39)	nFA (30-39)	53.3	50.2	yes
	FA (40-49)	nFA (40-49)	46.5	48.8	no
	FA (50-59)	nFA (50-59)	59.5	80.1	no
	FA (60-69)	nFA (60-69)	21.6	109	no
Education level	FA (Elementary)	nFA (Elementary)	57.7	69.9	no
	FA (Grade 7-9)	nFA (Grade 7-9)	35.1	49.6	no
	FA (Grade 10-12)	nFA (Grade 10-12)	62.8	56.0	yes
	FA (Higher)	nFA (Higher)	24.2	63.9	no
Pesticide experience	FA (1-9)	nFA (1-9)	61.5	43.4	yes
	FA (10-19)	nFA (10-19)	51.8	48.1	yes
	FA (20-29)	nFA (20-29)	48.1	59.5	no
	FA (30-39)	nFA (30-39)	32.9	98.7	no
Training	FA (with training)	nFA (with training)	43.7	89.3	no
	FA (without training)	nFA (without training)	50.5	23.6	yes
Location	FA (Al Musanah)	nFA (Al Musanah)	59.3	66.5	no
	FA (A'Suwaiq)	nFA (A'Suwaiq)	67.3	41.4	yes

Appendix 27. Mann-Whitney and Kruskal-Wallis analysis of FA (n=40) and nFA (n=120) respondents' responses to pesticide adverse effect on themselves and the effect of status, age, education levels, pesticides experience, training and location on respondents' responses.

Summary statistics on Ranks and Test Results

Variable*	Rank averages		H/U, P
Adverse effect	FA	nFA	
	80.1	80.6	2383, 0.944

Variable*								H/U, P
Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker	
	74.8	83.1	85.2	81.5	82.4	81.1	61.5	2.62, 0.855

Variable*											H/U, P
Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	60.5	81.1	86.7	78.0	83.8	77.2	82.9	85.7	72.9	60.5	7.08, 0.629

Variable*										H/U, P
Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher	
	60.5	86.7	85.7	74.5	78.9	75	84.3	80.1	82.6	3.84, 0.872

Variable*										H/U, P
Pesticides experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49	
	66.2	77.9	94.9	114	85.3	70.6	88	72.4	85.9	12.5, 0.129

Variable*					H/U, P
Training	FA with training	FA without training	nFA with training	nFA without training	
	75.7	80.7	94	80.3	0.56, 0.905

Variable*															H/U, P
Location	FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	
	72.0	70.1	64.5	68.1	59.9	54.5	72.2	54.5	81.3	84.5	75.3	110	106	91.4	20.6, 0.08

Appendix 27: Continued					
Pairwise Comparisons					
			Abs Mean		Statistical
	Factor 1	Factor 2	Rank Diff.	Threshold	Significance
Status	FA (Owner)	nFA (Owner)	6.64	45.8	no
	FA (Tenant)	nFA (Tenant)	0.68	39.5	no
	FA (Forman)	nFA (Foreman)	4.07	61	no
Age	FA (20-29)	nFA (20-29)	16.7	66.1	no
	FA (30-39)	nFA (30-39)	1.76	50.2	no
	FA (40-49)	nFA (40-49)	0.96	48.8	no
	FA (50-59)	nFA (50-59)	5.08	80.1	no
	FA (60-69)	nFA (60-69)	23.3	109	no
Education level	FA (Elementary)	nFA (Elementary)	14.5	69.9	no
	FA (Grade 7-9)	nFA (Grade 7-9)	2.4	49.6	no
	FA (Grade 10-12)	nFA (Grade 10-12)	5.54	56.1	no
	FA (Higher)	nFA (Higher)	8.09	63.9	no
Pesticide experience	FA (1-9)	nFA (1-9)	19.1	43.4	no
	FA (10-19)	nFA (10-19)	7.33	48.1	no
	FA (20-29)	nFA (20-29)	6.89	59.0	no
	FA (30-39)	nFA (30-39)	41.9	100	no
Training	FA (with training)	nFA (with training)	18.3	89.3	no
	FA (without training)	nFA (without training)	0.40	23.6	no
Location	FA (Al Musanah)	nFA (Al Musanah)	3.86	66.5	no
	FA (A’Suwaiq)	nFA (A’Suwaiq)	10.2	41.4	no

Appendix 28. Mann-Whitney and Kruskal-Wallis analysis of FA (n=40) and nFA (n=120) respondents' responses to use the PPE when spray pesticides and the effect of respondents' status, age, education levels, pesticides experience, training and location on their responses.

Variable*	Summary statistics on Ranks and Test Results (Rank averages)														H/U, P
Adverse effect	FA	nFA													
	71.7	83.4													2048, 0.165
Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker								
	75.9	63.8	84.2	86.3	80.6	81.0	112								6.11, 0.411
Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69					
	86.4	60.2	64.4	93.8	74.0	71.7	84.2	75.8	92.2	79.4					7.66, 0.569
Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher						
	86.1	78.4	65.0	75.0	69.8	84.6	78.8	87.3	91.8						5.58, 0.694
Pesticides experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49						
	71.8	70.3	78.9	55.2	86.1	79.6	76.4	97.6	85.5						4.56, 0.803
Training	FA with training	FA without training	nFA with training	nFA without training											
	98.1	67.9	117	82.6											5.80, 0.122
Location	FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	
	65.9	61.1	64.4	72.6	66.8	90.3	94.1	53.0	82.7	38.8	77.2	79.0	112	93.4	21.3, 0.067

Appendix 28: Continued					
Pairwise Comparisons					
			Abs Mean		Statistical
	Factor 1	Factor 2	Rank Diff.	Threshold	Significance
Status	FA (Owner)	nFA (Owner)	10.5	45.8	no
	FA (Tenant)	nFA (Tenant)	16.8	39.5	no
	FA (Forman)	nFA (Foreman)	3.17	61.0	no
Age	FA (20-29)	nFA (20-29)	14.7	66.1	no
	FA (30-39)	nFA (30-39)	24	50.2	no
	FA (40-49)	nFA (40-49)	11.5	48.8	no
	FA (50-59)	nFA (50-59)	1.60	80.1	no
	FA (60-69)	nFA (60-69)	5.4	109	no
Education level	FA (Elementary)	nFA (Elementary)	1.49	69.9	no
	FA (Grade 7-9)	nFA (Grade 7-9)	0.45	79.2	no
	FA (Grade 10-12)	nFA (Grade 10-12)	22.3	43.5	no
	FA (Higher)	nFA (Higher)	16.9	63.9	no
Pesticide experience	FA (1-9)	nFA (1-9)	14.2	43.4	no
	FA (10-19)	nFA (10-19)	9.30	48.1	no
	FA (20-29)	nFA (20-29)	2.54	59.5	no
	FA (30-39)	nFA (30-39)	42.4	98.8	no
Training	FA (with training)	nFA (with training)	19.1	89.3	no
	FA (without training)	nFA (without training)	14.6	23.6	no
Location	FA (Al Musanah)	nFA (Al-Musanah)	6.65	66.5	no
	FA (A’Suwaiq)	nFA (A’Suwaiq)	5.71	41.4	no

Appendix 29. Mann-Whitney and Kruskal-Wallis analysis of FA (n=40) and nFA (n=120) respondents' responses to read the label safety instruction and the effect of respondents' status, age, education levels, pesticides experience, training and location on their respondents' responses.

Variable*	Summary statistics on Ranks and Test Results (Rank averages)		H/U, P
Adverse effect	FA	nFA	
	121	67	777, < 0.001

Variable*								H/U, P
Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker	
	135	121	83	118	54.1	55.9	51.5	111, < 0.001

Variable*											H/U, P
Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	126	109	122	118	129	57.5	59.1	78.1	64.7	90.1	64.1, < 0.001

Variable*										H/U, P
Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher	
	130	94.4	110	137	131	63.7	56.9	66.8	63.9	79.8, < 0.001

Variable*										H/U, P
Pesticides experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49	
	119	114	128	144	55.8	73.2	71.1	85.1	104	68.5, < 0.001

Variable*					H/U, P
Training	FA with training	FA without training	nFA with training	nFA without training	
	144	118	102	66.1	60.2, < 0.001

Variable*															H/U, P
Location	FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	
	99.7	112	54.4	62.3	59.1	50	50	50	50	64.7	116	110	95	69.9	75.5, < 0.001

Appendix 29: Continued					
Pairwise Comparisons					
			Abs Mean		Statistical
	Factor 1	Factor 2	Rank Diff.	Threshold	Significance
Status	FA (Owner)	nFA (Owner)	17	45.8	no
	FA (Tenant)	nFA (Tenant)	67.2	39.5	yes
	FA (Forman)	nFA (Foreman)	27.1	61.0	no
Age	FA (20-29)	nFA (20-29)	68.7	66.1	yes
	FA (30-39)	nFA (30-39)	49.5	50.2	no
	FA (40-49)	nFA (40-49)	44.3	48.8	no
	FA (50-59)	nFA (50-59)	53.7	80.1	no
	FA (60-69)	nFA (60-69)	38.6	109	no
Education level	FA (None)	nFA (None)	66.6	92.7	no
	FA (Elementary)	nFA (Elementary)	37.5	72.2	no
	FA (Grade 7-9)	nFA (Grade 7-9)	43.4	52.4	no
	FA (Grade 10-12)	nFA (Grade 10-12)	73.6	57.9	yes
	FA (Higher)	nFA (Higher)	16.8	66.0	no
Pesticide experience	FA (1-9)	nFA (1-9)	63	43.2	yes
	FA (10-19)	nFA (10-19)	40.3	48.3	no
	FA (20-29)	nFA (20-29)	57.2	59.9	no
	FA (30-39)	nFA (30-39)	58.4	98.8	no
Training	FA (with training)	nFA (with training)	41.5	89.3	no
	FA (without training)	nFA (without training)	51.8	23.6	yes
Location	FA (Al Musanah)	nFA (Al Musanah)	37.4	66.5	no
	FA (A’Suwaiq)	nFA (A’Suwaiq)	53	41.4	yes

Appendix 30. Mann-Whitney and Kruskal-Wallis analysis of FA (n=40) and nFA (n=120) respondents' identification of label safety symbols of pictogram and the effect of respondents' status, age, education levels, pesticides experience, training and location in respondents' responses.

Variable*	Summary statistics on Ranks and Test Results (Rank averages)		H/U, P
Adverse effect	FA	nFA	
	121	66.9	766, < 0.001

Status	FA Owner	FA Tenant	FA Foremen	nFA Owner	nFA Tenant	nFA Foremen	nFA Worker	
	130	125	108	95.3	61.9	57.5	51	

Age	FA 20-29	FA 30-39	FA 40-49	FA 50-59	FA 60-69	nFA 20-29	nFA 30-39	nFA 40-49	nFA 50-59	nFA 60-69	
	133	126	124	91.6	120	43.6	62.9	79.5	65.3	71.1	56.6, < 0.001

Education level	FA Elementary	FA Grade 7-9	FA Grade 10-12	FA Higher	nFA None	nFA Elementary	nFA Grade 7-9	nFA Grade 10-12	nFA Higher	
	99.9	119	135	130	46.8	65.5	68.9	64.7	92.8	59.3, < 0.001

Pesticides experience	FA 1-9	FA 10-19	FA 20-29	FA 30-39	nFA 1-9	nFA 10-19	nFA 20-29	nFA 30-39	nFA 40-49	
	120	127	130	113	53.8	76.8	61.4	97.1	100	60.3, < 0.001

Training	FA with training	FA without training	nFA with training	nFA without training	
	126	124	49.5	66.3	48.6, < 0.001

Location	FA Al-Musanah	FA A'Suwaiq	nFA Barka	nFA Al-Musanah	nFA A'Suwaiq	nFA Saham	nFA Sohar	nFA Liwa	nFA Shinas	nFA Mhadah	nFA Ibri	nFA Bahla	nFA Bidiyah	nFA Al-Kamel	
	108	114.4	64.7	54.8	61.4	42.5	63.3	39.3	54.8	63.7	83.8	71.3	60.5	56.6	46.9, < 0.001

Appendix 30: Continued					
Pairwise Comparisons					
			Abs Mean		Statistical
	Factor 1	Factor 2	Rank Diff.	Threshold	Significance
Status	FA (Owner)	nFA (Owner)	35	45.8	no
	FA (Tenant)	nFA (Tenant)	62.9	40.3	yes
	FA (Forman)	nFA (Foreman)	50.6	57	no
Age	FA (20-29)	nFA (20-29)	89.5	66.5	yes
	FA (30-39)	nFA (30-39)	63.4	50.5	yes
	FA (40-49)	nFA (40-49)	44.9	48.9	no
	FA (50-59)	nFA (50-59)	26.3	80.6	no
	FA (60-69)	nFA (60-69)	48.9	110	no
Education level	FA (Elementary)	nFA (Elementary)	34.4	69.8	no
	FA (Grade 7-9)	nFA (Grade 7-9)	50.4	49.3	yes
	FA (Grade 10-12)	nFA (Grade 10-12)	69.9	55.5	yes
	FA (Higher)	nFA (Higher)	37.5	63.5	no
Pesticide experience	FA (1-9)	nFA (1-9)	65.9	43.4	yes
	FA (10-19)	nFA (10-19)	50.5	48.1	yes
	FA (20-29)	nFA (20-29)	69.1	58.6	yes
	FA (30-39)	nFA (30-39)	15.5	102	no
Training	FA (with training)	nFA (with training)	76.7	102	no
	FA (without training)	nFA (without raining)	57.5	23.5	yes
Location	FA (Al Musanah)	nFA (Al-Musanah)	53.3	66.5	no
	FA (A’Suwaiq)	nFA (A’Suwaiq)	53	41.4	yes

Appendix 31. Chi-square analysis of FA (n=40) and nFA respondents' in response to question: "has any organisation ever contacted you to inform you about which pesticides are allowed or not allowed"?			
	Yes	No	Marginal Row Totals
FA	13 (9.04) [1.73]	88 (91.96) [0.17]	101
nFA	5 (8.96) [1.75]	95 (91.04) [0.17]	100
Marginal Column Totals	18	183	201 (Grand Total)
The chi-square statistic is 3.8184. The p-value is .050692. Not significant at $p < 0.05$. The chi-square statistic with Yates correction is 2.914. The p-value is .087812. Not significant at $p < 0.05$.			

Appendix 32. Numbers and percentages of active ingredients found in FA (n=40) and nFA (n=120) farms based on their chemical groups.

Active ingredient	All farms			FA		nFA	
	Rank	N	%	N	%	N	%
Thiourea	20	10	0.8	4	0.8	6	0.7
Triazine	21	10	0.8	3	0.6	7	0.9
Mandelamide	22	9	0.7	2	0.4	7	0.9
Oxadiazine	23	8	0.6	0	0.0	8	1.0
Pyrazolium	24	7	0.5	4	0.8	3	0.4
Hydrazine carboxylate	25	6	0.5	3	0.6	3	0.4
Morpholine	26	5	0.4	0	0.0	5	0.6
Carboxamide	27	5	0.4	5	1.0	0	0.0
Phosphonoglycine	28	5	0.4	1	0.2	4	0.5
Sulfonylurea	29	3	0.2	0	0.0	3	0.4
Aryloxyphenoxypropionate	30	3	0.2	2	0.4	1	0.1
Cyclohexanedione	31	2	0.2	0	0.0	2	0.2
Biological	32	1	0.1	0	0.0	1	0.1
Benzilate	33	1	0.1	0	0.0	1	0.1
Chlorophenyl	34	1	0.1	1	0.2	0	0.0
Diacylhydrazine	35	1	0.1	1	0.2	0	0.0
Ethylene generator	36	1	0.1	0	0.0	1	0.1
Organohalide	37	1	0.1	0	0.0	1	0.1
Alkylchlorophenoxy	38	1	0.1	0	0.0	1	0.1
Pyridine	39	1	0.1	1	0.2	0	0.0
Quinoline	40	1	0.1	0	0.0	1	0.1
Semicarbazone	41	1	0.1	0	0.0	1	0.1
Spinosym	42	1	0.1	0	0.0	1	0.1

Appendix 33. Chi-square analysis of active ingredients found in FA (n=40) and nFA (120) respondents' farms based on manufacturers.			
	Me too	Basic producer	Marginal Row Totals
FA	54 (63.87) [1.53]	45 (35.13) [2.77]	99
nFA	66 (56.13) [1.74]	21 (30.87) [3.16]	87
Marginal Column Totals	120	66	186 (Grand Total)
The chi-square statistic is 9.1913. The p-value is .002432. Significant at $p < 0.05$. The chi-square statistic with Yates correction is 8.2838. The p-value is .004. Significant at $p < 0.05$.			

Appendix 34. Numbers and percentages of active ingredients sources (country of origin) found in FA (n=40) and nFA farms (n=120) (continue of figure 4.5).

Country of origin	Rank	All farms		FA		nFA	
		N	%	N	%	N	%
India	11	64	8.9	4	0.9	60	8
Spain	12	45	8.8	29	6.7	16	2.1
Denmark	13	44	8.3	25	5.8	19	2.5
Turkey	14	21	3.8	10	2.3	11	1.5
Malaysia	15	19	3.1	6	1.4	13	1.7
Austria	16	17	2.8	5	1.2	12	1.6
Italy	17	13	2.4	7	1.6	6	0.8
Canada	18	13	2.1	4	0.9	9	1.2
Cyprus	19	7	1.5	6	1.4	1	0.1
Belgium	20	8	1.4	4	0.9	4	0.5
Unknown	21	2	0.3	1	0.2	1	0.1
Hungary	22	1	0.1	0	0	1	0.1

Appendix 35. Retailers-based survey of pests and diseases diagnosis, pesticide use and pesticide risk awareness and safety.

<table>
<tr><td colspan="9">SECTION 1 - GENERAL INFORMATION</td></tr>
<tr><td>1.1</td><td colspan="2">Name of enumerator (interviewer)</td><td colspan="6">Mahmoud Al Nabhani</td></tr>
<tr><td>1.2</td><td colspan="2">Date of interview</td><td colspan="6"></td></tr>
<tr><td>1.3</td><td colspan="2">Interviewee's unique participant number</td><td colspan="6"></td></tr>
<tr><td>1.4</td><td colspan="2">Wilayat</td><td colspan="6"></td></tr>
<tr><td>1.5</td><td colspan="2">Village</td><td colspan="6"></td></tr>
<tr><td>1.6</td><td colspan="2">Location: N</td><td colspan="6">E</td></tr>
<tr><td colspan="9">SECTION 2 - THE FIRM AND RESPONDENT</td></tr>
<tr><td>2.1</td><td colspan="2">What is your status?</td><td>Owner</td><td>Seller</td><td>Worker</td><td colspan="3">Other (specify)</td></tr>
<tr><td>2.2</td><td colspan="2">What is your nationality</td><td colspan="6"></td></tr>
<tr><td>2.3</td><td colspan="2">How many years had the company being trading?</td><td colspan="6"></td></tr>
<tr><td>2.4</td><td colspan="2">Do you have other branches?
If yes, how many?</td><td colspan="6">Yes ☐1 No ☐2 Don't know ☐</td></tr>
<tr><td>2.5</td><td colspan="2">Who are the suppliers of the pesticides you sell?</td><td colspan="6">Importing ☐ Wholesaler ☐ Pesticide Company ☐ Others ________________</td></tr>
<tr><td rowspan="2">2.6</td><td rowspan="2">What is the highest level of education you have completed?</td><td>None</td><td>Elementary</td><td>Grade 7-8</td><td>Grade 9</td><td>Grade 10-12</td><td colspan="2">Higher education</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>2.7</td><td colspan="3">If answer 2.6 is higher educations, what certificate major do you have? (e.g Agriculture, Chemistry, Biology, Marketing, Others)</td><td colspan="5"></td></tr>
<tr><td>2.8</td><td colspan="3">Have you received any training in pesticides? If No go to 3</td><td colspan="5">Yes ☐ No ☐</td></tr>
<tr><td>2.9</td><td colspan="3">Who provided training in pesticide application? Enter code for trainer, If "Other", specify</td><td colspan="4">What training?</td><td>When</td></tr>
<tr><td></td><td></td><td colspan="2"></td><td colspan="4"></td><td></td></tr>
<tr><td></td><td></td><td colspan="2"></td><td colspan="4"></td><td></td></tr>
<tr><td></td><td></td><td colspan="2"></td><td colspan="4"></td><td></td></tr>
</table>

Appendix 35: Continued					
SECTION 3 - THE WORK EXPERIENCE					
3.1	Who are your main sources of information on pesticides?		MAF ☐ Farmers ☐ Pesticide suppliers ☐ Internet ☐ Others_____________		
3.2	Can you identify the problems shown in these photographs?		Which products would you recommend for control?	Dose	PHI
3.3	Whitefly	Yes ☐1 No ☐2 Not sure☐3			
3.4	Aphid	Yes ☐1 No ☐2 Not sure☐3			
3.5	Leaf miner	Yes ☐1 No ☐2 Not sure☐3			
3.6	Spodopteran	Yes ☐1 No ☐2 Not sure☐3			
3.7	Thrips	Yes ☐1 No ☐2 Not sure☐3			
3.8	Damping-off	Yes ☐1 No ☐2 Not sure☐3			

Appendix 35: Continued			
3.9	Melon decline	Yes ☐1 No ☐2 Not sure☐3	
3.10	Powdery mildew	Yes ☐1 No ☐2 Not sure☐3	
3.11	Downy mildew	Yes ☐1 No ☐2 Not sure☐3	
3.12	Early blight	Yes ☐1 No ☐2 Not sure☐3	
3.13	Late blight	Yes ☐1 No ☐2 Not sure☐3	
3.14	What is the percentage of customers buying pesticides solely based on your suggestions?		
3.15	What is the percentage of customers buying pesticides solely based on their own understanding?		
3.16	If you do not recognise a pest disease/crop protection problem, who helps you to diagnose the problem before you recommend a proper pesticide?		MAF ☐ farmers ☐ Pesticide suppliers☐ None ☐ Other (specify) ☐
3.17	If a farmer bought a pesticide from you and he comes back and says it did not control the pest/disease. What would you say/do?		Recommend another one ☐1 Increase the dose ☐2 Check application method / visit farm ☐3 Other__________☐4 Don't know ☐5
3.18	If a farmer bought a pesticide from you and he comes back and said that it no longer seem to be as effective as it used to be and the farmer or you suspect there might be pesticide resistance, what would you do/advise?		Recommend another one ☐1 Increase the dose ☐2 Check application method/visit farm ☐3 Other_______ ☐4 Don't know ☐5 No resistance occurs☐6
3.19	Are you aware of any pesticide Yes ☐ No ☐ resistance problems in your area?		If YES, which pesticide: Pest/disease:
3.20	Have you got any explanation as to why there might be a pesticide resistance problem?		

Appendix 35: Continued

	SECTION 4 – RISK, HEALTH AND SAFETY					
4.1	What possible risks do pesticides have?	None	Soil water	Livestock	Wild life	Humans
4.2	Do you explain to the farmer the possible risk of pesticides before selling?	Never	Rarely	Sometimes	Usually	Always
4.3	Do you take any protective measures during the loading/unloading/repackaging of pesticides?	Never	Rarely	Sometimes	Usually	Always
4.4	Have you ever noticed any adverse effect on yourself after handling pesticide?	Never	Rarely	Sometimes	Usually	Always
4.5	Do you read the safety instructions on pesticides labels before selling them?	Never	Rarely	Sometimes	Usually	Always
4.6	How do you deal with expired pesticides?	Dispose in Municipal site	Burying	Burning	Repacking	Change label
4.7	How you deal with empty containers?	Dispose in Municipal site	Burying	Burning	Use them for repacking	other

Look at the picture below.
Do you understand what any of the symbols mean? Tick if correct answer is given

4.8	4.9	4.10	4.11	4.12	4.13	4.14

4.15	Has any organisation ever contacted you to inform you about which pesticides are allowed or not allowed? If yes which (Enter code)	Yes ☐1 No ☐2 Don't know☐3

Appendix 35: Continued		
Section 5 – GENERAL COMMENTS		
5.1	Would you be interested in the results of my research survey? Can you give your contact number?	

Government/Commercial		**Farmer/Other**	**Literature/Internet**	
MAF	Extension (MAF)	FA Farmers' Association	**LA**	Label
C1	Extension (private)	**F5** Owner of farm	**L10**	Other (Book/leaflet/brochure)
C2	Seller/Supplier (Retailer)	**F4** Tenant	**L11**	Internet (specify)
C3	Seller (Manufacturer Rep.)	**F6** Foreman/manager	**L12**	Social media (eg WhatsApp)
		F7 Farm labourer		
		F8 Another farmer		
		F9 Other person (specify)		

Experience:	**E13 Own trial**	**E14**	**Crop monitoring**
(find out what this means)	**E15 Local/farm practice**	**E16**	**Common sense/other**

Appendix 36. Kruskal-Wallis and Mann-Whitney analyses of retailers' (n=75) ability to diagnose pests and diseases and the effect of respondents' status, year of trading, education levels, type of certificate, training, nationality and location on their responses.

Summary Statistics on Input Data

Variable	Rank Average									H/U, P
Status	Owner	Seller	Other							
	32.4	38	60							3.91, 0.14
Year of trading	≤5	6-10	11-15	16-20	21-25	26-30	>30			
	26.8	43	38.5	42.8	50.1	34	50.3			12, 0.062
Education level	Grade 9 and lower	Grade 10-12	Higher							
	32.3	30.6	48.2							11.7, 0.003
Certificate	Agriculture	Other certificate								
	46	33.2								434, 0.014
Training	With training	Without training								
	59.1	34.8								114, 0.001
Nationality	Bangladeshi	Egyptian	Jordanian	Omani	Indian	Sudanese				
	20.7	46.8	52.3	25	39.1	42				27.5, <0.001
Location	Barka	Al Buremi	Al Hamra	Ibri	Al Kamel	Al Khabourah	Saham	Shinas	A'Suwaiq	
	30	26.8	15.8	26.3	33.8	38.8	26.8	18	37.5	8.57, 0.380

Appendix 36: Continued					
Pairwise Comparisons					
			Abs Mean		Statistical
	Factor 1	Factor 2	Rank Diff.	Threshold	Significance
Education level	Grade 10-12	Higher education	17.5	12.6	yes
Nationality	Bangladeshi	Egyptian	26.1	23.8	yes
	Bangladeshi	Jordanian	31.6	21.1	yes
	Jordanian	Omani	27.3	21.5	yes

Appendix 37. Kruskal-Wallis and Mann-Whitney analyses of retailers' (n=75) proper pesticide selection and the effect of respondents' status, year of trading, education levels, type of certificate, training, nationality and location on their responses.

Summary Statistics on Input Data										
Variable	Rank Average									H/U, P
Status	Owner	Seller	Other							
	31.4	38.3	58.2							3.72, 0.160
Year of trading	≤5	6-10	11-15	16-20	21-25	26-30	>30			
	27.9	48	41.7	44.3	41.6	25.3	41			10.5, 0.107
Education level	Grade 9 and lower	Grade 10-12	Higher							
	42.5	33.1	42.1							3.27, 0.200
Certificate	Agriculture	Other certificate	No certificate							
	38.8	31.1	39.4							1.33, 0.510
Training	With training	Without training								
	51.7	35.9								189, 0.034
Nationality	Bangladeshi	Egyptian	Jordanian	Omani	Indian	Sudanese				
	26.3	47.1	49.2	24.1	38.3	37.6				18.7, 0.002
Location	Barka	Al Buremi	Al Hamra	Ibri	Al Kamel	Al Khabourah	Saham	Shinas	A'Suwaiq	
	26.9	30.8	8.50	28.1	34.8	41.5	39.5	24.4	35.1	9.58, 0.296

Appendix 38. Kruskal-Wallis and Mann-Whitney analyses of retailers' (n=75) ability to recommend proper dose rate and the effect of respondents' status, year of trading, education levels, type of certificate, training, nationality and location on their responses.

Summary Statistics on Input Data										
Variable	Rank Average									H/U, P
Status	Owner	Seller	Other							
	30.7	38.8	52.2							2.77, 0.25
Year of trading	≤5	6-10	11-15	16-20	21-25	26-30	>30			
	31.4	43	34	41.2	45.4	43.2	43			4.89, 0.558
Education level	Grade 9 and lower	Grade 10-12	Higher							
	31.5	39.9	35.6							1.14, 0.570
Certificate	Agriculture	Other certificate	No certificate							
	39.2	31.1	39.2							1.34, 0.510
Training	With training	Without training								
	37.9	38								324, 0.992
Nationality	Bangladeshi	Egyptian	Jordanian	Omani	Indian	Sudanese				
	34.8	49.1	39.5	27.3	36.8	34				7.77, 0.170
Location	Barka	Al Buremi	Al Hamra	Ibri	Al Kamel	Al Khabourah	Saham	Shinas	A'Suwaiq	
	22.5	39.8	9.33	31.3	37	41.3	48.9	30.9	32	14.8, 0.064

Appendix 39. Kruskal-Wallis and Mann-Whitney analyses of retailers' (n=75) ability to recommend proper PHI and the effect of respondents' status, year of trading, education levels, type of certificate, training, nationality and location on their responses.

Summary Statistics on Input Data

Variable	Rank Average									H/U, P
Status	Owner	Seller	Other							
	32.9	38.3	53.3							2.18, 0.34
Year of trading	≤5	6-10	11-15	16-20	21-25	26-30	>30			
	30.2	42.1	41.2	47.6	39.9	23.3	41			7.68, 0.262
Education level	Grade 9 and lower	Grade 10-12	Higher							
	27.6	35.5	43.1							3.62, 0.160
Certificate	Agriculture	Other certificate	No certificate							
	47.6	35	34.4							5.33, 0.070
Training	With training	Without training								
	47.3	36.6								232, 0.150
Nationality	Bangladeshi	Egyptian	Jordanian	Omani	Indian	Sudanese				
	29.3	49.7	46.3	23.1	38.9	33.8				16.9, 0.005
Location	Barka	Al Buremi	Al Hamra	Ibri	Al Kamel	Al Khabourah	Saham	Shinas	A'Suwaiq	
	27.2	33.3	14.8	22.6	28.2	41.5	38.4	18.8	38.5	11.7, 0.167

Appendix 40. Kruskal-Wallis and Mann-Whitney analyses of retailers' (n=75) ability to potential risks of pesticide and the effect of respondents' status, year of trading, education levels and training on their responses.

<table>
<tr><td colspan="9">Summary Statistics on Input Data</td></tr>
<tr><td>Variable</td><td colspan="7">Rank Average</td><td>H/U, P</td></tr>
<tr><td>Year of trading</td><td>≤5</td><td>6-10</td><td>11-15</td><td>16-20</td><td>21-25</td><td>26-30</td><td>>30</td><td></td></tr>
<tr><td></td><td>36.1</td><td>38.6</td><td>30.0</td><td>38.2</td><td>48</td><td>56</td><td>38</td><td>6.17, 0.404</td></tr>
<tr><td>Education level</td><td colspan="2">Grade 9 and lower</td><td colspan="3">Grade 10-12</td><td colspan="2">Higher</td><td></td></tr>
<tr><td></td><td colspan="2">42.9</td><td colspan="3">32.5</td><td colspan="2">43.8</td><td>5.82, 0.055</td></tr>
<tr><td>Training</td><td colspan="3">With training</td><td colspan="4">Without training</td><td></td></tr>
<tr><td></td><td colspan="3">34.4</td><td colspan="4">37.9</td><td>321, 0.960</td></tr>
</table>

Appendix 41. Kruskal-Wallis and Mann-Whitney analyses of retailers' (n=75) explanation of environmental risks of pesticide and the effect of respondents' status, year of trading, education level and training on their responses.

Summary Statistics on Input Data								
Variable	Rank Average							H/U, P
Year of trading	≤5	6-10	11-15	16-20	21-25	26-30	>30	
	29.3	35.9	34	42.6	51.9	61.2	40.6	12, 0.063
Education level	Grade 9 and lower		Grade 10-12			Higher		
	45.4		32.6			42.2		4.38, 0.110
Training	With training			Without training				
	48.8			36.3				217, 0.093

Appendix 42. Kruskal-Wallis and Mann-Whitney analyses of retailers' (n=75) response to reading safety instructions of pesticide label and the effect of respondents' year of trading, education level and training on their responses.								
Summary Statistics on Input Data								
Variable	Rank Average							H/U, P
Year of trading	≤5	6-10	11-15	16-20	21-25	26-30	>30	
	31.4	38.1	43.3	37.5	34.7	55	50.8	7.58, 0.271
Education level	Grade 9 and lower		Grade 10-12			Higher		
	35.5		27.7			44.6		12.1, 0.002
Training	With training				Without training			
	49				33.9			175, 0.032

Appendix 43. Kruskal-Wallis and Mann-Whitney analyses of retailers' (n=75) ability to identify safety symbols of label pictogram and the effect of respondents' year of trading, education level and training on their responses.

Summary Statistics on Input Data								
Variable	Rank Average							H/U, P
Year of trading	≤5	6-10	11-15	16-20	21-25	26-30	>30	
	33.3	40.1	48.9	30.8	45.6	37.3	38.7	6.96, 0.325
Education level	Grade 9 and lower		Grade 10-12		Higher			
	32.7		34.4		43.4			3.69, 0.158
Training	With training			Without training				
	39.8			37.7				307, 0.787